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A STUDY OF LENTICULAR IMPERFECTIONS IN THE EYES OF A SAMPLE OF MICROWAVE WORKERS AND A CONTROL POPULATION

Prepared by:

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A STUDY OF LENTICULAR IMPERFECTIONS IN THE EYES OF A SAMPLE OF MICROWAVE WORKERS AND A CONTROL POPULATION

by

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A JOINT STUDY FROM THE DEPARTMENTS OF

OPHTHALMOLOGY AND INDUSTRIAL MEDICINE

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ABSTRACT

An investigation was performed to compare the frequency of occurrence of lenticular imperfections in the eyes of a sample of 736 microwave workers and a control sample of size 559. The installations surveyed are described and their microwave safety procedures reviewed. The methodology for the ophthalmological examination, and for recording the extent of lens imperfections, are presented.

Microwave exposure was estimated by analysis of occupational history questionnaires. Ophthalmological observations of special clinical significance are presented and findings of this investigation are discussed.

SUBJECT: Evaluation of Contract AF30(602)-2215

1. The study accomplished by New York University-Bellevue Medical Center is the first intensive effort undertaken by RADC to study the effects of microwave energy on the human eye and to relate ophthalmological findings to actual conditions of exposure. In the absence of such data grave concern was often expressed that the current maximum permissible level (MPL) of 10 mw/cm^2 for unprotected personnel was excessive, and that prolonged exposure to such intensities would result in serious visual losses.

2. An important aspect of this study has been the determination that, in areas where accepted safety practices are observed, microwave workers do not reveal lenticular changes significantly different from those exhibited by an unexposed or "control" population. While sufficient incontravertible evidence is not yet available to establish a firm safety level, the results of this study suggest that the tissue damage threshold for long term exposure may exceed 10 mw/cm^2. Since the principal objective of the RADC microwave program is to establish and validate a realistic safety level for personnel exposure, this approach is in line with our long range plans.

3. The NYU-Bellevue study has additional implications for the conduct of follow-on animal research. For example, it has been shown that small lenticular imperfections such as granules, vacuoles and minute opacities are not necessarily precursors of damaging microwave effects. For this reason, new and more suitable criterial for specifying lenticular changes, together with appropriate measuring techniques, must be developed before extensive animal eye exposure series may be undertaken. Moreover, the observation that marked species differences exist with respect to the type and location of induced lenticular injuries now imposes the additional requirement that both criteria and examination techniques demonstrate the feasibility of extrapolating animal data to man.

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INTRODUCTION

This report describes a comprehensive study of a complicated and difficult problem. It will not be the last word on this subject but our hope is that it will add some knowledge and remove some fear. In addition, it should aid in programming the continuing investigations of the biological effects of microwave radiation.

This study represents a logical outgrowth of two previous series of investigations.

In the first series of investigations, the cataractogenic potentiality of microwave radiations in the laboratory animal under controlled environmental conditions had been clearly demonstrated.

Secondly, data obtained from an eye study survey of a group of employees at the Rome Air Development Center (1) was suggestive of an increased incidence of abnormal lens findings among microwave workers.

As a result of these studies, an ad hoc Eye Study Group was convened at the request of the Commander, Rome Air Development Center for the purpose of reviewing the lens findings of the Rome employees and of evaluating these findings in the light of the animal induced lenticular opacities.

The Eye Study Group determined (2) that the types of lens defects found at the Rome site are not different from the

types of lens defects noted in routine eye examinations, that such defects do not significantly interfere with vision and that technically the reported defects should be distinguished from cataracts in that a cataract represents a gross degree of lens opacification resulting in reduced visual acuity.

Herein lies one of the principal difficulties encountered. Many minute defects are spontaneously present in the lens and there has not been any correlation as to whether or not these early changes represent incipient cataracts. Some of these defects remain stationary for life. Others are associated with progression of opacification and ultimately result in cataract formation. When this occurs, the rate of progression is usually so slow that years may pass before the process is complete. Furthermore, this process of opacification may stop at an incomplete stage and thereafter remain stationary.

It should be noted that ophthalmologists do not ordinarily diagnose an eye as having a cataract unless loss of visual acuity has occurred or the defects in the lens are massive as compared to the defects found in the Rome group. Moreover, ophthalmologists do not routinely study the lens in great detail for minute defects. Furthermore, there is no standard method of conducting the slit-lamp examination nor of documenting the morphological and geographical findings.

The Eye Study Group recommended that the original survey should be expanded to include additional military personnel and that similar studies should be carried out on selected employee groups in electronic industries where exposure might exist, in order to obtain a larger sample of exposed individuals in order to develop more meaningful statistics; that the sampling procedure employed follow sound biostatistical practices and that if possible, the slit-lamp examinations involved should be accomplished by one ophthalmologist in order to insure uniform observations.

At this point, it is prudent to review some of the anatomical characteristics of the normal lens. The lens is entirely ectodermal in origin and at an early embryonic stage of development, the lenticular cells are isolated from the rest of the body by an envelope, its capsule. Although this tissue is isolated from the cellular components of the body, it continues to grow throughout life without any new cells entering the lens nor any lenticular cells leaving. Being avascular, the lens is at a disadvantage by not having as effective a cooling system as the other tissues of the body as well as not having available macrophages or replacement cells as occurs in the repair processes elsewhere in the body.

The lens is a biconvex, transparent tissue situated near

the anterior portion of the eye. lying directly behind the iris in the primary axis of the eye. Its diameter is less than 1.5 centimeters and its thickness from anterior to posterior pole is less than 5 millimeters. In the center of the lens is the earliest portion, the fetal nucleus. This is surrounded by the adult nucleus, which in turn is surrounded by the cortex. Lining the anterior surface of the lens is a 1 cell thick layer of epithelial cells which extends to the equatorial region, where peripheral epithelial cells undergo transformation into lens fibre cells. The peripheral surface of this tissue is enclosed by an inert transparent capsule.

Due to the optical qualities of the eye, the lens can be examined by a slit lamp. This instrument is a type of biomicroscope having a light beam which can be altered in size and intensity. In addition, the light may be focused upon any level of the lens concurrently with the viewing microscope so that although the lens is transparent, the portion brought into focus may be examined. By slit-lamp examination, the various regions of the lens may be recognized and imperfections noted.

Injury to any portion of the lens may result in loss of transparency, a condition termed opacification. This may occur in localized regions of the lens or diffusely throughout

the lens substance. When opacification has been established, it may remain stationary throughout life; it may progress or after partially progressing, it may become stationary.

Sporadically, cases of cataract formation in humans who have been exposed to microwave radiations have been reported. These cases have exhibited extensive, dense opacification which represents the end result of massive lens damage. Some of these patients have been followed closely by ophthalmologists who have attempted to determine whether causal relationship existed.

Two complicating factors arose in evaluating the available human material. The first of these was the possibility of mixed microwave and ionizing radiation exposures. Both types of radiations can produce lens opacification. For this reason as well as the need to specify microwave exposure, evaluation of the environmental history is very important.

The second factor requiring consideration was the lack of a standardized method of examining the lens as well as a lack of uniformly recording the findings of such an examination. Certain minute lens defects occur normally and there is no agreement amongst ophthalmologists as to nomenclature regarding these defects and as to whether or not these early changes represent incipient cataracts.

Thus, we were brought to a realization of the inadequacy of previous methods of investigating the available human material and to a realization of the importance of establishing a parameter of hazard associated with microwave radiation. It was imperative to design our study in such a manner that it would be meaningful and biostatistically sound.

Our study was designed with the hope that it could accomplish the following objectives:

1. Establish a standardized method of slit-lamp bio-microscopic examination of the crystalline lens of the eyes.

2. Examine "exposed" and control personnel to determine the extent, if any, of cataract formation and to report all types of lens defects along with their geographic locations.

3. Evaluate environmental data relating to microwave and ionizing radiations as concerns the subjects studied.

4. Advise whether or not an eye health problem exists.

5. Provide a detailed description of the methods of surveying for microwave and ionizing radiation exposure in the various establishments participating in our study.

6. Critically review these procedures.

7. Develop improved methods of characterizing the exposure histories of personnel.

8. Prepare recommendations which, if adopted, would lead to a more uniform method of performing environmental surveys, a unified procedure for reporting the data, and, hopefully, the establishment of a registry of environmental data which, when correlated with the accumulating clinical information, will assist to interpret the relationships that exist between the environmental and clinical findings.

Preliminary studies were made to establish a standardized method of slit-lamp examination in association with the use of the Donaldson stereo-camera which photographs the lens of the eye in stereopsis. By combining these two methods of study, it was possible to document many types of lens defects, especially those defects having potential clinical significance.

Concommitantly environmental exposure history questionnaires and biostatistical criteria for selecting exposed

and control subjects were developed. These criteria will be presented herein.

Following initial examination of a group of workers at the Rome Air Development Center, the entire ophthalmological problem was re-evaluated and the following findings were noted:

1. Every lens examined has imperfections.

2. Detailed examination of the most heavily exposed patients at RADC failed to reveal any pathognomonic lens defect.

3. To be significant, defects must be of such a nature of magnitude that they can readily be verified by slit-lamp examination or documented by photography.

At the same time, the original Rome Eye Study Survey was examined statistically and expressed in graph form relating the total number of lens defects per lens plotted against age. In the control group, this graph clearly demonstrated a linear function (3).

Satisfied that we could express the eye findings in a numerical fashion, estimate the exposure by scoring technique and relate the two by statistical analysis, the procedure for obtaining the sample and insuring a blind ophthalmological study was put into operation.

This investigation was based upon the sample of the

exposed group being as representative as possible of personnel employed in a permissible microwave environment. However, because of our interest in the problem of microwave cataract, two individuals suspected of having this condition were privately referred to the ophthalmologist during the course of this investigation and he was thus afforded the opportunity of establishing this diagnosis and determining the manner in which exposure to microwave radiation induces cataracts. These findings along with a review of the literature will be reported separately.

This investigation has been undertaken under Contract AF 30 (602) 2215 with the Rome Air Development Center at the recommendation of the Tri-Services Microwave Committee. In addition to the Army, Navy, and Air Force, many industrial companies participated and without their cooperation, the study would have been meaningless. To all, we express our deep appreciation.

A final word is in order regarding the statistical methodology. In the construction of the mathematical models, one must be aware that the purpose of the model is to provide theoretical conclusions which then are subjected to a test before being accepted. If there had been no models,

the complex conclusions attempted herein could never have been conjectured. A good model will fit more facts than a poor one, but no model can be perfect. For this reason, it has been necessary to critically evaluate the mathematical expressions from the viewpoint of clinical credibility.

I

DESCRIPTIONS OF INSTALLATIONS SURVEYED

The samples of microwave workers and controls included in the overall study were selected from sixteen separate installations. The work at these installations encompasses a variety of types of microwave operations including research and development, operation, installation, maintenance, and test of microwave equipment.

The survey included samples from installations located in eight states in the United States and in one foreign territory. A geographical breakdown of the survey reveals that nine of the installations visited were located in the northeast, three in the far west, two in the southeast, one in the extreme northwest, and, one visit was made to a United States installation on foreign territory.

Eight of the sites in the survey are military installations, four being controlled by the Air Force, three by the Navy, and one by the Army. The samples of radar workers from most of these military sites include both military personnel and civilians employed either by the government or by government contractors. The other seven installations are operated by private industry, six of them by electronics companies and one by a chemical company utilizing microwave radiation in a non-radar research capacity.

A breakdown of the total sample according to job classification is shown in Table I-1. The most frequent types of microwave work encountered in this study, in order of decreasing frequency, are operation, installation, and testing of microwave equipment (73%), followed by research and development (12%).

Two of the eleven installations were visited during preliminary stages of the investigation, and the data obtained from them has not been included in the statistical analysis presented in this report. The data from one other installation was incomplete, necessitating its elimination from the analysis.

Table I-1 categorizes the thirteen sites included in the analysis of the data, according to the type of installation and the major function of each. In each case, when possible, detailed descriptive information was collected with particular interest being given to work practices, sampling fraction, types of microwave equipment in use, and microwave safety practices.

Installation A

Installation A is a large military establishment where microwave operations are divided between research and development of high-powered search radar equipment and the maintenance of airborne radar equipment. One hundred forty-eight microwave workers and one hundred forty-seven controls were

examined.

The personnel at Installation A may be divided into two groups, those engaged in research and development, and those in airborne radar maintenance. The research and development work is mainly performed by civilian employees of the government; and, due to the nature and requirements of the work, this group generally has a higher mean age and more exposure to microwave radiation than the aircraft maintenance group which comprised the majority of the sample. This group was mainly composed of young service personnel with less microwave experience than the civilian group. The types of exposures of this group result from testing and aligning procedures on aircraft radar.

Surveying of microwave hazards is handled by an on-site unit whose duties are concerned with microwave measurements of various kinds. This group surveys possible sources of overexposure on request of on-site operating personnel. The surveying procedure follows a service directive (4) which specifies the delineation of safe distances in regards to the 10 mw/cm^2 limit. The directive also lists the complete specifications of the test equipment and specifies the method of calculation to be used and the procedure to be followed in each survey. The

surveying procedure thus appears to be well standardized.

Installation B

This installation is a civilian microwave assembly plant employing approximately fifty microwave workers. Nineteen microwave workers and twenty controls were examined. The microwave worker group was chosen by company supervisors as representing those individuals at Installation B with past and present microwave exposures of varying degrees.

The plant function is mainly design and assembly of microwave modulators. All transmitter tubes are purchased from other manufacturers and incorporated into the assembly at this installation. There is no tube testing performed at this installation.

Airborne radar transmitters and receivers are regularly tested in specially designed environmental rooms constructed to simulate high altitudes. The negative pressure within the rooms limits entry during operation of microwave equipment and decreases the possibility of personnel exposure. The walls of the chambers are lined with steel plates such that transmission to the environment is minimized.

Test chambers with wire mesh exteriors and nonreflecting interiors (rubberized horsehair mats) are also used to test

transmitter performance. There is no restriction on access to these rooms during operation of the radar equipment.

Some work is being done with X band radar indicating the possibility of high power densities in very limited areas (pencil beams).

The majority of the antenna work is restricted to low powers estimated to be in the microwatt region. Higher powered transmitters and antennas have been used in the past, but no radiation surveys were made at that time.

In general, the low powers involved and the use of environmental and shielded chambers suggests that high level exposures would not now be expected at this installation.

There is no regular microwave surveying procedure being used. No survey instruments have been designated to check power densities and there is no systematic procedure for requesting surveys or reporting the findings of a survey. In the event of an expect X-ray exposure, film badges are issued. This is not done on a routine basis.

Installation C

Installation C is a large military missile tracking facility at wh seventy-five microwave workers and thirty-eight controls were examined. The total number of microwave workers at this

site is approximately one hundred. The sample was chosen partially on the exposure history questionnaire data and also by the subjective judgement of the supervisory personnel at Installation C.

The microwave workers may be divided into civilian and military employees. The civilians may be further broken down into two groups. One group consists of workers employed by companies doing contract work for the government. The other group is comprised of civilians directly employed by the government.

The radar equipment is generally medium to high power (i.e., >100 watts average output) and exists in a variety of types which include: tracking radar, mobile van units, airborne radar, radar beacons, radar jammers, and shipborne radar.

Due to the great variety in radar types, a quantitative classification of radar exposures for each individual is impossible, as was generally the case in this study. Sites of possible exposure are around the antennas of the higher powered equipment. Remote radar equipment, which is not well supervised or surveyed, appeared to offer the greatest probability of over-exposures. Certain areas in which men worked in close proximity to radiating antennas have been surveyed and found to exceed the maximum acceptable exposure levels of

10 mw/cm^2. Such findings have led to the designation of exclusion areas or relocation of equipment to reduce the power density to levels that conform to the 10 mw/cm^2 specification.

Responsibility for the surveying of possible radiation hazards rests with a testing and monitoring group. This group performs microwave power density surveys at the request of the director of the specific operation in question or at the request of the health officer. The survey is performed according to a standard procedure followed in evaluating possible radio frequency hazards at this installation. The areas of power densities greater than 10 milliwatts per square centimeter are located and all personnel are excluded from such areas. In addition to the microwave surveys, the transmitters are sometimes surveyed for X-radiation levels.

A detailed report of each survey is written and distributed to both the group requesting the survey and to the group responsible for overall site safety. In general, the surveying and reporting procedure appears adequate to protect the workers from microwave radiation hazards where the surveys are performed. The possibility of over-exposures in unsurveyed areas exists due to the fact that the radar equipment is deployed over a wide area and is in some cases mobile.

Installation D

Installation D is a smaller military missile tracking site. The majority of the microwave workers at this installation work for civilian contractors who install, operate, and maintain missile tracking and area clearance radar for the military. Approximately fifty men are employed in microwave work at site D. Of this group, fifteen were examined along with eight controls. The microwave workers were selected on the basis of availability rather than on the basis of the microwave history questionnaire.

Many of the radar installations at this site are remotely located and staffed by a small group of men who function more or less independently of other groups. At each of these locations, there is the possibility of exposure to ionizing and microwave radiation from the transmitters and microwave exposure from the antennas. Film badges have been issued to all employees at this site. There is no group available on a continuous basis to perform radiation surveys.

Installation E

Operations at Installation E include research and development of advanced radar systems for missile detection. There are also tube producing facilities, antenna development projects,

electromagnetic scattering experiments, and fabrication of field evaluation models at this installation.

The total number of people employed in microwave work at Installation E is eight hundred. Thirty-one microwave workers and twenty-five controls were examined. The exposed group as selected by company representatives is comprised of individuals with varied degrees of microwave exposure.

Although there is a wide variety of possible sources of microwave exposure, the generally low powers should tend to minimize the operating hazards The testing of microwave components is generally carried out in specially designed rooms lined with rubberized horse hair to reduce power spray. The process of antenna testing is performed out of doors with the antennas mounted on towers. The antenna power outputs are normally of the order of microwatts and there is small likelihood of overexposures from antenna radiations. Frequencies up to a maximum of 12.5 kilomegacycles per second are used.

In the event of a suspected microwave radiation hazard, the supervisor in charge of the equipment requests a hazard survey. The survey is supervised by the head safety engineer. Power densities in excess of 10 milliwatts/cm^2 of microwave radiation (at any frequency from L band and up) are considered

hazardous and such conditions are corrected. The surveys are performed with a Ramcor detector.

A survey report is made to the head safety engineer and the supervisor who requests the survey. Such survey results are kept on file by the safety department.

Installation F

Installation F is a civilian company engaged in contract work for the government. Radar defense systems are developed, tested, and operated at this site. There are approximately three hundred microwave workers at this site. One hundred microwave workers and thirty-seven controls were examined at site F. The microwave workers were chosen by the company as representing those individuals with suspected microwave exposures of varying degrees.

The operation of very high powered radars at Installation F is a source of potential exposure. Such equipment has been provided with safety interlock systems to avoid exposure to the high power densities associated with the antennas.

Installation G

Installation G is a large civilian research and development laboratory engaged in military and civilian microwave work. The

military work involves research, development, fabrication, and testing of missile guidance systems. The work at this part of the laboratory involves the operation of some high powered radar sets (i.e., $>$ 1 Kw average power). The number of employees engaged in microwave work at this site is approximately four hundred.

The civilian work, which is performed at a separate site, is mainly concerned with lower powered communications systems ($<$ 10 watts average power). This work involves research, development, and testing of microwave communications networks. There is some communications work on tropospheric scattering being carried out that involves higher power outputs (i.e., $>$100 watts average power). The number of employees engaged in microwave work at this site is approximately one hundred.

The sample of microwave workers examined at Installation G was chosen on the basis of the duration of past microwave experience. The total number of microwave workers examined was forty-four. This sample was composed of thirty-five men from the site engaged in military work and nine men from the civilian branch.

The company has set up a standard procedure for the evaluation of microwave hazards and for the protection of the workers.

In the event there is an operation that may present a hazard, the project engineer directly in charge of the operation assumes the responsibility of avoiding overexposures. On the basis of the known operating characteristics of the equipment, he makes use of standardized safe distance formulas to delineate the hazardous areas. These areas are designated as radiation hazard areas and are fenced off. The power density levels are then checked with survey meters to insure that the calculations are accurate in defining the radiation area.

Since the calculations may be made before the equipment has been turned on, this procedure appears to be safer than commencing operation without knowledge of the possible hazards involved.

The level of 10 milliwatts per square centimeter is specified as being potentially hazardous. A level of less than 1 mw/cm^2 is attained whenever possible since this is considered safe by this company for indefinitely prolonged exposure or permanent assignment.

Installation H

The work at this civilian installation is mainly fabrication and testing of radar equipment.

The total number of employees engaged in microwave work is approximately four hundred. The sample examined consisted of

forty microwave workers and forty-one controls. More detailed information is not available.

Installation I

Installation I is a civilian operation devoted to research and development of surface and navigational radar.

The total number of workers actively engaged in microwave work at this installation is approximately one hundred. The sample consisted of fifteen microwave workers and seventeen controls. The exposed group chosen by the company represents individuals with possible past and present exposure to microwave radiation.

This installation is one part of a large industrial radar complex. Each part is autonomous in regard to specific details of microwave safety administration, but all installations follow a general company safety policy. The executive safety organization makes recommendations which are mandatory only in the case of the existance of decided hazards. The executive group, therefore, serves mainly in an advisory capacity.

The research and development work performed at Installation I does not generally involve high power densities although there is some equipment with power outputs in the kilowatt range which is infrequently operated. During operation of this high powered equipment, the radiating antenna is located on the roof which is

made an exclusion area. There are no interlocks on the doors leading to the roof and exclusion is accomplished by means of warning signs, lights, and buzzers. There were a few antenna exposures to the individuals working on the roof or working directly on the antennas, but no apparent damage has been noted.

The research work eventually leads to the construction of a prototype to be used for development. The surface radar prototypes are the kilowatt transmitters previously mentioned. Since most of this work involves L band equipment, there is little chance of encountering small beams of very high power densities. A limited amount of testing of low power output equipment is performed in anechoic chambers. Experimental work is being carried out to develop power absorbing drums to serve as dummy loads, or anechoic chambers for high powered equipment. Such equipment would decrease the use of outside antennas for transmitter testing and thereby reduce the hazards associated with free space irradiation in heavily populated areas. These drum loads are being developed for use with transmitters, having power outputs greater than 10 kilowatts.

At Installation I the safety administrator works with the head project development engineer in formulating a microwave safety program. The execution of the safety program is a joint effort on the part of the safety department and the project

engineer directly involved with the problem.

The program is generally similar to that at Installation G and is well specified in a company directive. This directive outlines areas of responsibility, and establishes control over all equipment which generates or carries RF within any of the installation facilities. The safety administration at Installation I has decided to establish a maximum exposure level to RF radiation of 1 milliwatt per square centimeter average power density. This level was decided upon since it was felt that inaccuracies involved in the use of microwave field intensity survey meters warranted an increase in the safety factor, and also because it was felt that this level could be maintained in most instances without undue difficulty or expense.

The department managers are given prime responsibility for ensuring the safe operation of equipment. They also must see that the necessary coordination has been obtained with the facilities safety office prior to the operation of any RF equipment.

The project engineer directly involved with the project is responsible to the department manager for submitting pertinent operational characteristics data for the RF source to the safety office. These data include peak and average power, pulse duration, operating frequency, antenna dimensions, gain

and radiation pattern as well as a calculation of the theoretical tentative outer limits of the radiation hazard zone. This calculation is made by use of the standard far field formula as specified in TO-31-1-80 (4). This serves as a basis for a preliminary radiation control plan which may be used to decrease the hazards associated with the initial measurements of power density.

The project engineer must then assist the safety personnel in making power density measurements on the equipment. He must submit a final radiation control plan to the safety office for their approval. Copies of the approved report are then retained by the safety office and the project engineer.

The power density surveys are performed by an environmental survey group that works with the safety office and the project engineer. Four different types of instruments are available for these surveys. The choice of instruments depends upon the type of equipment being monitored as well as upon instrument availability at the time of the survey request.

Ionizing radiation surveys are also carried out according to standard procedures and the regulations of the Federal Register are followed. All individuals who it is thought may possibly be exposed to ionizing radiation are issued film badges, and permanent dosage records are kept by the safety office. There have been no significant exposures to ionizing

radiation recorded to date.

Installation J

Installation J is a remote missile tracking facility with one very high powered source of microwave radiation. The work at this installation is mainly operation and maintenance of this radar equipment.

There are approximately two hundred men engaged in RF work at this site. One hundred and forty-two of these men were examined along with sixty two controls.

There are three large antennas located roughly along the perimeter of a 90° segment of a circle of one-half mile radius. These antennas are elevated approximately 20 feet, thus decreasing power densities near the ground. The total radiated power is in the megawatt region, but since large radiating surfaces are involved, extremely high power densities are not encountered in the vicinity of the antennas.

The antennas are located approximately one-half mile from the living quarters and main work areas, thus reducing the likelihood of significant levels of environmental RF radiation. Metal enclosed corridors are used for external connections to the antenna buildings, thus permitting access to these buildings with minimum exposure to rf radiation.

A detailed radiation survey has been performed by a survey

team at the installation to delineate rf hazard and controlled areas. This survey was also performed to compile data regarding rf intensities within the safety fence which has been built around the rear of the antennas. The survey included all areas within the safety fence to which personnel require access.

Power density measurements were made at approximately fifty ground level locations in each of the three antenna sectors and also on the roofs of the transmitter buildings in front of the antennas. In all cases, field intensity measurements were made with calibrated RCA MI-30411 Field Intensity Meters which were specially designed for the microwave frequency at this installation. The maximum intensity noted within an approximate two-minute period was taken as the effective level at that point. Horizontal and vertical components were measured separately.

The measurements were used to designate controlled areas and hazardous areas. A controlled area is an area where the RF power density is between 1 and 10 mw/cm^2, and a hazardous area is where the RF power densities are 10 mw/cm^2 or greater. Areas where the RF power density is below 1 mw/cm^2 are not considered dangerous to personnel.

The survey resulted in the specification of hazard areas between the scanner buildings and the antennas, and also at the front of the roofs of the buildings. Other roof areas and

ground areas around the antennas were designated as controlled areas and were posted with warning signs. It was recommended that access to these areas during operation of the radar generators should be permitted only with a safety escort and RF protective clothing.

The interiors of the transmitter buildings adjacent to the antennas have been surveyed for RF and X radiation. Standard surveying procedures have been established such that each day one of the transmitter modules is surveyed with a RF meter as well as an ionizing radiation meter. Those individuals who regularly work in close proximity to the modules wear film badges. The surveys in general reveal very low levels of RF radiation (i.e., microwatts) and X radiation. The areas around the top of the module where levels of X radiation greater than 10 mr/hr are encountered, are designated as radiation hazard areas and are posted with warning signs. All work in these areas must be performed with the guidance of a safety representative who monitors for X and RF radiation. It is usually possible to turn off a specific module before commencing work so that the danger of exposure is minimized.

Installation K

The main use of radar at Installation K is missile tracking and area surveillance. The installation is composed of a

missile launching area and an associated military base located approximately 15 miles apart. There are six remote monitoring stations located on islands down range from the launching site. There are also four radar tracking ships located in the down range area.

The initial sample has been chosen from the group working in the missile launching area and the military base. The overall operation of this installation is undertaken by a civilian contractor. The sample consists of civilians working for the contractors or sub-contractors and also a group of military personnel from the base.

Safety representatives of the groups concerned, selected the personnel to be included in the exposed group. The selection was made on the basis of present association with radar equipment. This group, therefore, represents the majority of the radar workers at Installation K.

The majority of the radar equipment is located in the launching area which explains the larger size of this group with respect to the group at the military base. In general, the exposure histories indicate that the personnel exposure at the launching area is greater than at the military base. This is due to the fact that the missile launching group is composed mainly of civilians with more radar experience than the military group.

Approximately one hundred and fifty individuals located on the down range islands and forty shipboard personnel have not been included in the present study. Of this group, possibly 80% or more are radar personnel with present and past radar experience.

The radar equipment located in the launching area is used primarily for search and tracking. It is generally high powered long-range radar with effective radiated powers in the kilowatt and megawatt regions.

The radars are spread out over a large area and are not near those areas where the majority of the non-radar personnel work, thus decreasing the probability of exposure to these individuals.

The radar equipment areas are fenced off for security and safety reasons, and areas of radiation levels approaching 10 mw/cm^2 are posted with warning signs. The standard rf hazard sign is not used in all cases to designate these areas. Ionizing radiation hazard signs have been substituted for the rf hazard signs in some locations.

A special sub-contractor group has been formed for frequency control and analysis of range operations at the missile launching area. This group undertakes the assessment of all rf radiation hazards in this area.

This group has undertaken an analysis of rf power density

levels at the site in relation to ordinance devices, biological effects, and fuel.

In regard to the biological effects of the rf sources at the missile launching area and the military base, calculations and measurements were made to delineate possible hazard areas. The distance from each instrumentation site where the power density equals or exceeds 10 mw/cm^2 has been calculated for the level present in the main beam of the antenna. In many instances, locations closer to the radiating source will not be subject to the calculated power level since the antenna cannot irradiate the areas in question. The calculations, therefore, include this additional factor and allow a greater margin of safety.

The calculations were performed by using the method specified in T.O. 31-1-80 (2). These calculations take into account the reduced gain of the antenna in the Fresnel Region and, therefore, also include a safety factor.

The calculated levels were checked by a survey group at some of the radar sets by means of a power meter and calibrated antennas. In all cases, the measured values were found to be less than the theoretically predicted power density levels. In some cases where the formulas indicated the existance of a hazard distance, actual measurement indicated that no

hazard existed at any distance from the antenna.

It was concluded that, in order to avoid unnecessary risks, power density levels which were suspected or observed to be equal to or greater than 10 mw/cm^2 should be considered hazardous areas. Normal access to these areas should be prevented by warning signs and personnel should be admitted to these areas only under emergency conditions, and even then, for the minimum possible duration.

It is also stated that where test procedures required free space radiation, the radiating device should be orientated in such a manner as to avoid directing the beam toward areas inhabited by the public or personnel. The primary beam should be directed such that personnel in adjacent areas are not exposed to the main beam or to side lobes of the main beam.

Additional surveys have been performed since the initial one to update necessary safety procedures, but not all sites have been surveyed at the present time. A survey of all equipment not previously checked is proposed for the near future. This will provide a reference for the control of rf biological hazards for the entire installation.

The equipment at the military site is used for search purposes, communications, and to a limited extent, for tracking. One installation, which is operated solely by the military, is

used exclusively for air search purposes and has an entirely separate mission from the rest of the installation. The transmitting antenna associated with this equipment is housed in a radome. The power density levels in the radome are considered hazardous and access to it during operation is not permitted. Due to the need for continuous operation of this equipment, there are indications that personnel occassionally enter the radome during operation for a short period of time (i.e., less than one minute). Ionizing radiation surveys have been performed on the transmitter and dosimeters have been issued. A microwave power density survey has been made on the roof of the control building and hazard areas have been designated.

Overall access to this area is limited to those individuals assigned to the equipment.

It appears that, in general, exposures to microwave radiation at this site and the launching area will be limited to those individuals directly involved with the radar equipment. This is not necessarily the case at the remote tracking stations and on board ship.

The overall safety precautions, and the awareness of the radar personnel to the exposure problem, appear adequate enough to preclude the occurrence of overexposure to microwave radiation at Installation K during routine operations.

Installation L

The sample location designated as Installation L is a U.S. Navy vessel which is equipped with a number of high powered navigation, fire control, and search radar systems. The shipboard personnel includes an electronics group which operates and maintains the shipboard radar equipment. There are approximately fifty men in this group who are directly involved in radar work.

The sample of radar workers was chosen on the basis of the data obtained from the microwave history questionnaires, but there were certain limitations imposed on the sample selection since approximately one-half of the radar groups was on shore leave at the time of the examination. The majority of the radar group on duty at the time were examined. This group, which consisted of twenty-six individuals, was approximately age matched with a control group of twenty-seven non-radar shipboard personnel.

The proximity of the radar equipment to all of the members of the ship's crew had the effect of complicating the selection of a non-exposed control group. It was decided to select the control (whenever possible) from those personnel whose duty stations normally kept them below decks during operation of the high powered radar equipment. Although this procedure was followed in selecting the control group, it is not certain that all of the controls had not been exposed to some degree of microwave radiation.

The majority of the radar equipment is located above deck level in the ship's superstructure. The higher powered equipment includes three sets generating greater than 500 kw peak power and one other set generating greater than 200 kw of rf power. The antennas are located some forty feet above deck level and are provided with cut off switches to prevent irradiation of personnel in other deck areas. The rf power densities in certain parts of the upper superstructure have been found by measurement, to exceed 10 mw/cm^2. Personnel are normally excluded from these areas during operation of the radar generators.

Measurements of power density are performed by a special group of naval personnel who make intermittant surveys when requested or when excessive levels are suspected. No surveying is performed by shipboard personnel on a routine basis.

Installation M

The primary activities relating to microwave radiation work at Installation M are research and development, and training of personnel in the operation and maintenance of military surface search radar and microwave communications equipment. This installation is operated by the military.

The sample of sixty-four microwave workers examined represents approximately 40% of the total complement of microwave workers at this site. The group was composed of twenty-one research and

development personnel, and forty-four personnel from the training division. A control group of approximately the same size was selected for the two microwave workers' groups. The control group contained fifty-five non-radar workers.

The radar equipment used by the training group is generally of moderate to low power (i.e., <100 watts average power output). The equipment which is located in close proximity to or inside the teaching areas, is not operated on a continuous basis.

The nature of the research and development work at Installation M precludes the release of information related to most of the equipment specifications. One long range radar set was in operation at the time of the survey. This equipment, although of high power (i.e., >10 kw) had been completely surveyed for r.f. power density without the detection of any significant levels.

MICROWAVE SAFETY PROCEDURES

The opportunity has been afforded to observe the microwave safety programs in effect at the various installations visited during the course of this study. As a result, it has been possible to make some general observations relating to these programs. No attempt has been made to make specific recommendations relating to the microwave safety program at any one installation.

In general, the type of program at a given installation varies according to the function and amount of equipment and also to a certain extent upon the type of personnel responsible for microwave safety. Individuals engaged in general safety or industrial hygiene work are often not intimately connected with radar operations and frequently are concerned with a radar hazard when it is drawn to their attention by the individuals who work with the radar. Satisfactory safety programs in this event depend upon close cooperation between these groups. It, therefore, appears desirable to have an individual (or group of individuals) on a supervisory level, whose concern and awareness of possible microwave radiation hazards will result in proper cooperation between technical and safety personnel.

A procedure which appears to afford a good opportunity for the cooperation of safety and technical personnel would consist of a two step check on all radar operations at a given installation.

The initial analysis of the possible hazards associated with a given radar set could be made by the engineer directly in charge of the development and/or operation of the radar set, at the request of his supervisor. This analysis could be a theoretical analysis based on the known or expected generating characteristics of the equipment. The results of this analysis, which would serve as an indication of the possible degree of hazard associated with the set, would then serve as a reference for the safety supervisor. If so indicated by this initial analysis, safety procedures could immediately be decided upon and further analyses of the actual magnitude of the hazard could then be undertaken by safety personnel. This analysis would consist of a power density survey and the specification of controlled access or exclusion areas, properly designated as microwave radiation hazard zones. Consideration would also have to be given to the existence of X radiation in the vicinity of the r-f generating tubes.

In a number of instances noted during this study, it appeared that the lack of adequate exchange of information between safety and technical personnel may have resulted in undesirable conditions. This was particularly true in the cases where radar sets were operated in areas which were remote from the main installation. The operating personnel at these remote locations, not being directly under safety supervision, may have had a greater tendency to overlook the microwave safety regulations. In some

instances, again due to the remoteness of the locations, the safety procedures were not well defined. Therefore, it appears that responsibility for microwave safety should directly involve the technical supervisor at the remote site as well as the installation's microwave safety group.

The techniques and instruments used to determine microwave radiation power density levels at the installations visited were found to vary appreciably. There does not appear to be any general agreement among individuals engaged in microwave safety as to the reliability or accuracy of the various commercially available power density measuring devices. In certain instances, it has been found necessary to design microwave survey instruments to be used with a specific type of radar generator. Although this procedure may appear to be an expensive approach, it may be necessary under certain circumstances where accurate and reliable measurements are required.

The most striking lack of non-uniformity noticed among the safety procedures at the various installations visited during this survey was the designation of microwave radiation hazard areas. Warning lights, buzzers, bells, and signs of various types were used to designate microwave hazard areas at these installations. The fact that different methods were used to draw attention to the exclusion areas does not appear to be as important as the lack of

uniformity in regard to the marking of the radar hazard zones which could lead to much confusion among individuals, such as maintenance personnel, who are not familiar with radar operations. In some cases, ionizing radiation warning signs or high voltage signs were used to delineate microwave radiation areas.

This lack of uniformity of designation of microwave hazard zones can most likely be attributed to a lack of information concerning the existence of a standard radio-frequency hazard sign. The standard warning sign, which is shown in Figure 1-1, is worded "Danger RF Radiation Hazard." The lettering is in bright red and the background, a vivid yellow. In order to avoid confusion, it is recommended that this sign be used exclusively to designate microwave radiation hazard areas.

The general conclusion based on survey of microwave safety procedures is that the programs are adequate to prevent overexposure to rf radiation under routine conditions.

II

METHOD OF OPHTHALMOLOGICAL EXAMINATION

The ophthalmological examination included history, visual acuity, slit-lamp examination of the lens and stereo-photography of the lens. In addition, other ophthalmological procedures such as tonometry, ophthalmoscopy and outline perimetry were performed when indicated.

Part I Ophthalmological History

The ophthalmological history was oriented towards gathering information relating to hereditary predisposition toward cataract formation and in order to elicit past history of pathological conditions predisposing the patient to secondary cataracts.

Part II Visual Acuity

The visual acuity was recorded without eyeglasses and with eyeglasses where worn in order to determine any loss of vision due to cataracts. Whenever corrected vision was less than 20/20, ophthalmoscopy was performed to determine etiology.

Part III Slit-Lamp Examination

Slit-lamp examination was performed and the results were scored and recorded in accordance with the protocol established to evaluate the sub-clinical microscopic lens defects as noted by the Rome Eye Study Group. Five categories of slit-lamp observation were defined. Minute defects, opacification and

relucency describe the microscopic appearance of the total lens volume. Sutural defects and posterior polar defects describe specific regions of the lens.

1. Minute defects- This category included all defects such as granules, vacuoles and tiny opacities which are ordinarily too small to be individually catalogued.

2. Opacification- Before becoming clinically cataractous, the lens undergoes changes in that either an irregularly diffuse cloudiness develops or discrete regions of the lens, bordering macroscopic dimensions, become markedly opacified such as occurs when increased radial markings verge on spoking.

3. Relucency- Optical luminosity occurs when the beam of light from the slit-lamp traverses the lens and the various regions such as the cortex to adult nucleus to fetal nucleus to adult nucleus to cortex may be distinguished from one another by the differing degrees of haziness and the light reflexes created by the light beam.

4. Sutural defects- The sutures of the human lens can usually be observed by slit-lamp examinations. As this region of the lens is prominently involved in experiment 1 microwave cataracts produced in certain laboratory animals, it was mandatory to specifically include this region of the lens as a category for investigation. Thickening, banding and striations of

the lens fibers of this region were noted as sutural defects.

5. Posterior polar defects- The posterior subcapsular cortex, especially in the polar region, is a frequent site and apparently a sensitive region in the lens for early changes to occur regardless of the type of injury to the lens. Moreover, in some cases of ionizing radiation injury, it is pathognomonic for a doughnut-shaped subcapsular defect to appear and progress to the stage of polar, subcapsular cataract.

Each of these categories of slit-lamp examination were graded on a relative scale similar to the method employed in using the slit-lamp to evaluate the degree of flare or number of cells in the anterior chamber in the following manner: 0 for insignificant numbers of degree, 1 for small numbers or minor degree, 2 for moderate numbers or degree, 3 for large numbers or major degree short of clinically recognized cataract.

Part IV Stereo-photography

Stereo-photography of every lens by means of the Donaldson camera was performed as part of the routine examination. By this procedure, it was frequently possible to document macroscopic changes in the lens providing the plane of the lens to be photographed was precisely in the focal plane of the camera. The focal plane of the camera was determined by the examiner

vertically aligning two verging target lights in the plane of the patient's lens that was to be photographed. This was accomplished by having the patient's head fixed in a chin-forehead rest. He was then instructed to stare directly ahead and to keep his palpebral fissure open. At this time, the camera operator, while viewing the target lights as they entered the patient's eye, adjusted the camera by first visually lining up the axis of the camera to the axis of the eye by moving the pedestal holding the camera to approximately the proper place. Next, the photographer had to adjust the height of the camera so that the target lights were approximately on a level with the axis of the lens. Following this, an adjustment was made in the horizontal meridian to align the camera with the axis of the eye. Finally, the target lights were brought into adjustment for the proper antero-posterior plane of the lens and at this instant, the photographer tripped the shutter.

III

ESTIMATION OF EXPOSURE HISTORIES OF MICROWAVE PERSONNEL

The questionnaire which has been described previously (3) was used throughout the course of the study to reconstruct the exposure histories of microwave workers. It was intended to separate exposed from controls and also to facilitate the grouping of exposed personnel into several classes according to the relative severity of exposure to microwave radiation.

The questionnaire, which consists of seven parts, is included as Appendix III-A.

Part I

Part I is an employment record. This section attempts to obtain a complete account of employment in microwave work and the duration of employment at each specific job. The types of work are divided into five categories and the examinee indicates the number of months spent working in each category. The total duration of microwave work as well as the duration of work in each category of employment are recorded.

Part II

Part II attempts to determine the existence and location of film badge records of ionizing radiation exposure to the examinee.

Part III

Part III is included to take into account the possibility of X-ray exposure from high voltage microwave generating tubes. It

is requested that the examinee indicate any work experience involving high voltage generating tubes from which X-ray shielding had been removed. An indication of the time periods involved and transmitter tube voltages is requested to give a general idea of the magnitude of the possible exposure to ionizing radiation.

Part IV

In Part IV, detailed information regarding the principal types of microwave generating equipment with which the examinee has worked is requested. The following information concerning the parameters of microwave exposure is requested:

a. type of equipment

b. average power generated

c. operating frequency or frequency band

d. duration

e. date of first exposure

f. mode of power termination

g. distance from equipment

h. type of work

Part V

Part V regards the practice of looking into energized microwave waveguides. Since this practice may result in direct exposure of the lens to microwave radiation, it is considered of

importance in this survey. The frequency of this practice as well as the average power being generated and the method of viewing the waveguide is recorded.

Part VI

Part VI is a record of the number of times the examinee has physically sensed exposure to microwave radiation from the waveguide or transmission line. The average power and frequency of the source of radiation is requested.

Part VII

Part VII refers specifically to exposure to rf radiation from the antennas of microwave generators. Information regarding duration of work at different positions around the radiating antenna, as well as power and frequency specification are requested. A question is also included to determine the frequency of experiencing heating sensations as a result of antenna irradiation.

In addition to recording exposure histories, the questionnaire has been used to assign a semi-quantitative exposure index to each examinee for purposes of dividing the exposed subject into two or more classes according to the severity of their exposures. The scoring system is shown in Table 3-1. The exposure index assigned to each employee is obtained by

taking the product of items 1 x 2 x 3 x 4 and adding this to the product of 5 x 6 x 7. With this system, it is possible to attain a maximum score of 81.

As a result of experience with the questionnaire and the exposure index, it is now possible to critically evaluate its effectiveness for the gathering and categorization of microwave exposure histories.

Questionnaire Evaluation

The main difficulty encountered in the use of the questionnaire to the inherent difficulties in an attempt to obtain information of the type sought. In many instances, the employee was not able to supply detailed information regarding his work experiences either because of a lack of knowledge, security restrictions, or inability to remember. This was particularly true of nonprofessionals such as technicians and operators.

Some inconsistencies were noted in the answers to certain related questions. In certain cases, ambiguous wording in the questionnaire led to confusion and errors in the answers to some of the questions. A list of explanatory remarks which has been used to clarify the questionnaire is shown in Appendix III-B.

It became apparent after using the questionnaires that in most instances, extensive personnal interviews would be required

to get accurate and complete information. In many cases, interviews were conducted in order to supplement the information obtained by use of the questionnaire.

The data from the completed microwave history questionnaire, as well as from the separate eye scoring form, were transferred to a master code sheet. The details of the coding system used are given in Appendix III-C. In the coding process, it was not possible to transfer all of the information from the history questionnaire. In certain cases, therefore, the information from the questionnaire was categorized and then coded.

The information was then transferred from the code sheets to IBM cards to facilitate subsequent statistical analysis by means of a computer.

IV

STATISTICAL ANALYSIS OF THE

RELATIONSHIP BETWEEN EYE SCORE, AGE, AND ENVIRONMENTAL FACTORS

1. Sample Analysis

A. Age Frequency Distribution

The age frequency distributions of the microwave workers' group and the control group are important because they are one means of judging the similarity of the two sample groups. Ideally, for a study of this type, an exact man-for-man age match of exposed to controls would be desired. This type of age matching would eliminate the element of bias due to differences in age frequency distributions. Unfortunately, due to sampling restrictions attributed to the difficulty of obtaining adequate controls, it was not possible to age match on a man-to-man basis. This resulted in the selection of a control group which is approximately 14% smaller than the microwave workers' group and, in spite of the generally good agreement between mean ages of the two groups (i.e., $\bar{X}$ exposed = 32.76, $\bar{X}$ controls = 33.20), there are differences in the age frequency distributions.

The age frequency distributions of the exposed (microwave workers) group and the control group are given in Table 4-1 and the relative frequency histogram of the age distributions is shown in Figure 4-1.

A comparison of the shapes of the relative frequency histograms reveals that these distributions are not as similar as would be desired. There is a noticeable peak in the exposed group distribution in the age range of 26 to 30 years which is absent in the control group. There is also a noticeable difference in the distributions in the age range 41-45 years of such a nature that proportionatly, more controls fall into this age group than exposed (i.e., 11.5% vs. 8.2%). The effect of these dissimilarities can be overcome to a certain extent if the statistical analysis is age adjusted but in the event that there is no age adjustment, the results may be affected. This age effect will be further discussed in section IV-3-F where its influence in the Chi-square analysis of the individual eye score categories is considered.

B. Eye Score Frequency Distribution

The relative frequency distributions of the eye scores for the two groups are presented in Table 4-2 and shown in Figures 4-2a and 4-2b. In both exposed and control groups, the relative frequency histogram indicates a bi-modal distribution of eye scores with peaks at score 4 and 8 for the exposed and 4 and 7 for the controls. A minimum exists between these peaks at a score of six in both instances. This bi-modal

distribution indicates that one or more of the individual eye score categories is distributed differently from the others. This possibility is supported by the distributions shown in Figures 4-6 to 4-10. Analysis of the individual categories reveals that the distribution of posterior polar defects differs appreciably from the other categories in that the maximum relative frequencies are found at a score of zero. This, therefore, appears to explain the shape of the relative frequency histogram since the increased frequency of zeros in the posterior polar defects category has the effect of super-imposing a peak at score four on the total relative frequency eye score histogram.

C. Exposure Score and Duration of Microwave Work Frequency Distributions

The relative frequency distributions of exposure score and duration of microwave work are given in Table 4-3 and 4-4 and are shown in Figures 4-3 and 4-4.

The relative frequency distributions of exposure score and duration of microwave work, with the exception of category one, are generally similar in shape as would be expected since they should be correlated. The difference in category one is most likely attributable to the exclusion of a number of individuals from the analysis whose exposure score was less than or equal

to three. The exclusion from the sample was based on the incompleteness of the exposure information for those individuals.

The median duration of microwave exposure for the sample is approximately three and one-half years. Thirty-seven per cent of the sample has worked three years or less in microwave employment and the greatest relative frequency occurs in the 0-19 month category. In effect, therefore, a significant fraction of the sample of microwave workers consists of individuals who might not be expected to be truly representative of the population of chronically exposed microwave workers due to the short duration of microwave employment and the general awareness of microwave hazards during their employment. Since an estimate of the average duration of microwave work in the total microwave worker population is not available, it is not possible at this time to determine how representative this sample is, but it does not seem that the results obtained from the study of this sample would overestimate the difference in the frequency of minor lens defects existing in the total population of microwave workers as compared to non-microwave workers.

D. Job Classification Distribution

The frequency distribution of types of microwave work is given in Table 4-5. The three main job classifications encountered

in this survey are (1) operation of microwave equipment plus installation maintonace and test 33%, (2) installation and maintenance 29%, and (3) research and development 12%.

Since those three categories of employment include the main types of microwave work which could be expected to result in microwave radiation exposure, it appears that the sample is well balanced in regard to the types of workers examined.

It is not possible to state that this frequency distribution is representative of the general microwave population since the overall job category frequency distribution for the total microwave population is not presently available.

E. X-ray Exposure

The fact that an individual did or did not wear a film badge is not necessarily an indication of whether he was exposed to ionizing radiation. It is well known that some microwave workers have worked near inadequately shielded generating tubes without their having been provided with film badges. It is also well known that conservative managements provide film badges in many instances where minimal or no possibility of X-ray exposure exists.

Of the total sample, about 17% indicated that they had worn film badges at one time or another. A total of 43% had

histories which suggested the possibility of some exposure to ionizing radiation.

2. Statistical Analysis of Microwave Lens Data

A. Summary of Total Lens Score Data

The data obtained from the examination of the lenses of a total group of 736 microwave workers and 559 controls has been subjected to linear regression analysis. This analysis reveals that the regression of eye score on age differs significantly for the two groups. At all ages considered in this study, the exposed group had the higher mean total eye score. It was also found that the rate of increase of these minor lens defects was significantly greater in the exposed group, thereby resulting in increasing differences in mean eye score with increasing age (see Figure 4-5).

B. Statistical Analysis

The linear model selected for the analysis of the exposed and control groups is:

Expected value of $Y = \mu = \beta_o + \beta_1(X-\bar{X})$

Estimated value of $\mu = \hat{Y} = b_o + b_1(X-\bar{X})$ where,

Y = eye score

X = age

β_o, β_1 = regression coefficients, and b_o, b_1 are their "least squares" estimates.

1) Exposed Group

$$\hat{Y}_e = 0.6376 + 0.1814X_e$$

and

s = standard error of the estimate $(\hat{Y}_e)$ =

$$= \pm s_p \left[\frac{1}{N_e} + \frac{(X_e-\bar{X}_e)^2}{SXX_e} \right]^{\frac{1}{2}}$$

$$= \pm 0.06389 \text{ (at } X_e = \bar{X}_e = 32.765 \text{ yrs.)}$$

2) Control Group

$$\hat{Y}_c = 0.9670 + 0.1584\ X_c$$

and

$$s = \pm s_p \left[\frac{1}{N_c} + \frac{(X_c-\bar{X}_c)^2}{SXX_c} \right]^{\frac{1}{2}}$$

$$= \pm 0.0745 \text{ (at } X_c = \bar{X}_c = 33.2075 \text{ yrs.)}$$

A plot of these equations is shown in Figure 4-5. The age range of the plot has been restricted to the age range of the individuals included in the study (i.e., 20 to 60 years) and these relations apply to this range only.

A test was performed to determine the statistical significance of the difference in regression coefficients (i.e., β_1's) and it was determined that these coefficients are different for the exposed and control groups at a level of significance of

2.5% (i.e., $P < 0.025$). (See Appendix IV-A).

This difference in regression coefficients has the effect of increasing the difference in exposed and control groups with increased age. At twenty years of age, which is approximately the age at which an individual commences work in the microwave field, there is little if any difference in the mean eye score between exposed and controls, but with progressive exposure to microwave radiation, this difference tends to increase.

In order to determine the statistical validity of the difference in mean eye scores between the two groups, a specific age was selected and the hypothesis that there was no significance to the difference in the eye score at that age was then tested. This hypothesis was rejected at a .05% level of significance ($P < .0005$) when tested at the mean age of the two groups. (See Appendix IV-B). This implies that a statistically highly significant difference in mean eye scores was detected in this study.

3. Analysis of the Data from the Group Examined After October, 1961 (i.e., Since the Last Report)

The data from the group examined since the last progress report (i.e., October, 1961) was analyzed in the same manner as the total group. The following results were obtained:

1) Exposed Group

$$\hat{Y}_e = 0.0890 + 0.1606X_e$$

and

s = standard error of the estimate ($\hat{Y}_e$)

$$= \pm s_p \left[\frac{1}{N_e} + \frac{(X_e - \bar{X}_e)^2}{SXX_e} \right]^{\frac{1}{2}}$$

$$= \pm 0.09130 \ (\text{at } X_e = \bar{X}_e = 31.5096)$$

2) Control Group

$$\hat{Y}_c = 0.9753 + 0.1323X_c$$

and

$$s = \pm 0.1054 \ (\text{at } X_c = \bar{X}_c = 34.3163)$$

These equations were plotted as shown in Figure 4-5-b and it is noted that, due to the greater value for the regression coefficient for the exposed group, and the slightly lower mean eye score at the lower ages, these two graphs intersect with the exposed group showing the greater mean eye score at greater age values.

The difference in the values of the regression coefficients (i.e., β_1's) was subjected to a statistical test and it was found that the difference calculated for these groups was significant ($P < 0.05$). (See Appendix IV-C).

The difference in mean eye score for the two groups was also tested at two ages. It was found that the difference in

mean eye score for the two groups at the overall mean age of $\overline{X} = 32.7133$ was not significant but the difference at $X = 60$ years was found to be significant ($P < 0.05$). (See Appendix IV-D).

4. Individual Eye Score Category Frequency Distributions

The total eye score has been broken into its five components and the frequency distributions of each have been determined as shown in Table 4-7. There are some noticeable differences in the distributions of some of the classes of lens defects, which may be an indication that some of these categories of lenticular imperfections are associated with microwave exposure.

Because of the limitations of the scoring system, for the individual categories, (i.e., only four possible scores: 0,1, 2,3) a rigorous statistical analysis, of the type used above, would not be too meaningful in the determination of the significance of these differences in individual category scores.

The data was therefore subjected to a chi-square analysis in which the significance of differences in the distribution of exposed and control group scores in each category are determined. The chi-square values for the five lens categories are shown in Table 4-8.

A. <u>Minute Defects</u>

The mean minute defects score for the exposed group is slightly greater than for the control group (i.e., mean score exposed group = 1.666; mean score control = 1.618). The chi-square value is 2.620 with 3 degrees of freedom. This value

is not significant at the 5% level ($P > .05$), and the slight difference in minute defects between the exposed and control groups is shown to lack statistical significance.

B. Opacification

The mean opacification scores for the exposed and control groups are 1.58 and 1.47, respectively. The chi-square value is 10.2 which indicates that there is a difference in the distribution of opacification scores which is significant at the 2.5% level ($P < .025$). Since the exposed group has the greater mean opacification score, this difference may possibly be related to the specific effects of microwave radiation on opacification changes in the lens.

C. Relucency

The mean relucency score for the exposed group is 1.56 compared to 1.54 for the control group. The chi-square value for relucency is 0.207. This value is not significant at the 5% level.

D. Sutural Defects

The frequency distributions of sutural defects for the exposed and control groups show no obvious differences in shape. This is also noted in reference to the mean scores which are very nearly equal. The mean sutural defects scores are 1.19

and 1.21 for the exposed and control groups, respectively. The chi-square value is 1.075, which is not significant at the 5% level.

E. Posterior Polar Defects

The shapes of the posterior polar defects histograms indicate that there may be a more appreciable difference in the relative number of posterior polar defects between the exposed and control group than any of the other minor lens defect categories. The skewed distribution of posterior polar defects among the exposed and controls is the only distribution of this configuration noted in any of the lens categories. The increased frequency of zero suggests that posterior polar imperfections occur relatively infrequently in comparison to the other types of lens changes noted in this study.

Fifty-two per cent of the exposed group and 63% of the control group received posterior polar scores of zero. The sutural defects category, which has the next highest percentage of zero scores, shows 10% and 9% zero scores for the exposed and control group respectively. This indicates that on the average, at least five times as many individuals (either exposed or controls) will have insignificant numbers of posterior polar defects as compared to the number having insignificant numbers or degrees

of other lens changes (i.e., minute defects, relucency, sutural defects, opacification).

There also appears to be a marked difference in the posterior polar defects of exposed and controls. The percentage of exposed individuals with posterior polar defects scores of two or greater is 13% compared to 3% for the controls. Therefore, it is on the average, about four times more probable that an individual who receives a posterior polar defects score of two or greater is a member of the group exposed to microwave radiations.

The chi-square value is 38.540. This value is highly significant ($P < .0005$) and is suggestive of a relative degree of specificity of this type of lens change for microwave radiation exposure.

F. Discussion and Conclusions

The chi-square analyses performed in this section unfortunately do not take into account variations in the mean ages or age distributions of the exposed and control groups. However, since it has been demonstrated in a previous section of this report that the average number of these minor lens defects increases with age, it would be expected that a group of greater mean age would have a greater number of minor lens defects irrespective of microwave exposure. In this sample,

as discussed in section IV-1, the control group has both the greater mean age and the greater proportion of older individuals which should have the effect of decreasing any actual difference in the two groups due to microwave exposure. If age adjustment were made, the chi-square values would be expected to increase due to this effect, but it is improbable that the significance of any of the results would be altered.

The results of the analysis, therefore, suggest that the lens categories which may be indicators of exposure to microwave radiation are posterior polar defects and opacification. The other categories (i.e., sutural defects, minute defects, and relucency) have not been shown to differ in the exposed and control groups analyzed in this study.

5. Analysis of the Feasibility of Periodic Lens Examinations to Monitor Microwave Exposure Effects

An analysis has been performed in an attempt to determine the feasibility of periodic lens examinations, of the type described in this study, to monitor the microwave exposure effects on a group of microwave workers. The possibility of such a procedure is suggested by the progressive increase of lens defects with age noted in the analysis of the data. Since the average number of lens defects in the microwave workers' group has been shown to increase more rapidly than the

controls, the difference in the lenses of these two groups would be expected to increase with time at a rate related to the degree of exposure to microwave radiation.

In the determination of the feasibility of period lens examinations as a means of monitoring microwave exposure effects, it is necessary to consider the variation of the difference in mean eye score of the exposed and control group with time. An estimate of the expected increase in the difference in mean eye scores for exposed and control groups, δ , may be obtained by considering the difference in the regression coefficients estimated by the total sample data (i.e., $b_E = 0.1814$, $b_C = 0.1584$). The estimated expected difference per year is therefore 0.0230 eye score units. In order to be reasonably certain of detecting an increase in the difference in mean eye score for the two groups, an interval must be chosen which results in a change in this difference which is significantly greater than the expected variance in the measurements. The details of the analysis are presented in Appendix IV-E.

In the case of the total group of 736 microwave workers and 559 controls, a minimum observation interval of 16.5 years between examinations would be required to detect true expected increase in the eye score difference of 0.38 eye score units with a 0.8 probability. If the group were composed of one hundred

microwave workers and one hundred controls, then the probability of detecting this same increase would be only 0.2 and an interval of forty-three years between examinations would be required for a 0.8 probability of detection. Correspondingly, if a 0.9 probability of detection were desired, then an interval of 19.5 years would be required for the above combined group of size 1,295 and an interval of fifty-three years would be required for the group of size two hundred.

It is evident that the length of the interval between examinations, in all of these cases, is of such magnitude that the use of this technique to monitor exposure to microwave radiation does not appear to be feasible for a group such as the one selected for this study. However, in a group of microwave workers in which the average exposure was greater than in this group, the mean number of minor lens defects should diverge more rapidly from the control group, thereby permitting the observation of a significant change in a reasonable length of time. An exposed group of this kind, of the necessary size, would unfortunately be difficult to assemble and even more difficult to follow over any length of time greater than a few years. Increasing the size of the group would decrease the time between examinations, but it would also make control over the sample much more difficult even for short periods.

The increase in the difference in minor lens defects for the exposed and control groups, although not appearing to offer a feasible monitoring procedure in this instance, could possibly be of value if a more sensitive, non-subjective method of determining the rate of increase of minor lens defects with age could be developed. This system could be applied in such a manner that the expected increase in mean eye score for a large group of "average" microwave workers would serve as a basis for comparison of any other group of microwave workers at a given installation. Significant deviations from the expected eye score at a given time would be an indication that some or all of the microwave workers at an installation were being exposed more than the average and depending upon the magnitude of the deviation, corrective action might be indicated.

V

OPHTHALMOLOGICAL OBSERVATIONS OF SPECIAL CLINICAL SIGNIFICANCE

During the course of performing the slit-lamp examinations, several patients exhibited findings meriting special consideration. Most of these have been reported previously (3) and, at this time a follow-up report is available for two of them,--one exhibiting intumescent lenses (A) and the other exhibiting microwave cataracts (B).

A. Intumescent Lenses, Follow-up

A one year follow-up examination was obtained on one of the two individuals with a finding of bilateral intumescent lenses. This individual had received an accidental exposure to levels of microwave radiation which are said to have substantially exceeded 10 milliwatts per square centimeter. This exposure took place the week prior to the original examination. Two days after the original examination, his lenses were no longer intumescent and appeared normal. One year later (during which time this man continued to work as a microwave employee), re-examination revealed that both lenses were normal and no evidence of pathology was present. The posterior polar subcapsular cortical regions of his lenses were unremarkable at both examinations.

B. Microwave Cataract, Follow-up

This patient was seen in consultation and, therefore, not included in this statistical study. However, as he demonstrated an early clinical stage of microwave cataract formation, his case was mentioned. Follow-up examination revealed that the immature cataract of the right eye had progressed to hypermaturity and that the incipient cataract in his left eye had progressed to the stage of immature cataract. In the incipient and immature stages of development of these cataracts, the posterior polar subcapsular cortical regions of both lenses were unremarkable.

C. Microwave Cataract, New Case

A second patient seen in consultation and therefore not included in this statistical study was examined and found to have microwave cataracts, the right eye more advanced than the left.

It has been estimated by the safety personnel at this patient's place of employment that the probability exists of repeated short duration exposures to levels of microwave radiation exceeding several hundred milliwatts per square centimeter and that his cumulative exposure to ionizing radiation was less than 1 roentgen.

A good continuing follow-up examination schedule has been maintained on this patient. The cataract of his right eye

developed to the stage where surgical correction was required and the cataract of his left eye has not yet progressed to this stage of development. At no examination has the posterior polar subcapsular cortical region of either lens been noted to be pathological.

D. Unrelated Ophthalmological Findings

It is of interest to note that no eye abnormalities, other than those normally expected in a group of this size, were encountered. A random appearance of such conditions as amblyopia, trauma, etc. occurred. In addition, two unsuspected cases of glaucoma were discovered by means of these examinations.

DISCUSSION

A. The principal objective of this study has been to determine whether or not personnel currently employed as microwave workers were developing cataracts at a greater rate than a similar population not so exposed.

It is important to bear in mind that, at no installation, was it possible to establish exact qualitative data concerning past exposure to microwave radiation. Thus it was meaningless to attempt a quantitative analysis of the actual levels of microwave exposure.

All that may be stated concerning the personnel examined in this study is that the population can be divided into two groups, namely, microwave workers and approximately age-matched controls. Moreover, it is also apparent that the group of microwave workers may well not be a truly representative sample of all personnel employed in microwave environments.

Due to these limitations, it is not valid to draw any generalized conclusions concerning whether or not 10 milliwatts per square centimeter is a permissible level of microwave radiation. The only question concerning this standard is whether or not personnel known to have been exposed to higher levels should be excluded from this survey because it is known that acute lens

injury can occur from higher levels and that, subsequently, one cannot attribute observations on such individuals to chronic effects. The procedure decided upon in this study was therefore to exclude individuals who were known before hand to have suffered acute lens injury due to microwave exposure.

Fortunately, no case of microwave cataract was found in this study. This is not to be construed so as to indicate that microwave radiation may not produce cataracts. The etiology of microwave cataract appears to be thermic in nature and the pathogenesis of this type of cataract will be reported in a separate publication.

B. In III ESTIMATION OF EXPOSURE HISTORIES OF MICROWAVE PERSONNEL, the inaccuracies of this method of reconstructing exposure histories are discussed. Moreover, a list of explanatory remarks to clarify the questionnaire was required and interviews were finally conducted for many but not all of the sample. In the coding process, it was not possible to transfer all of the information independently so that certain of the information was categorized. A semi-quantitative exposure index was obtained by taking the sum of two multiplicand products. However, simple inspection of the factors and relative weight in Table 3-1 shows that this system of scoring exposure is inadequate in some respects.

C. In IV, STATISTICAL ANALYSIS OF THE RELATIONSHIP BETWEEN EYE SCORE, AGE AND ENVIRONMENTAL FACTORS, it becomes apparent that a number of questions have arisen in analyzing the data.

.. Although many types of mathematical models could have been selected, the linear expression was chosen because preliminary studies suggested such a relationship (3). Furthermore, it has been shown that this is the most feasible model to express the aging process for other physiological functions (5).

2. It is stated that the age frequency distributions of the exposed and control group were not ideally age-matched and therefore, although the mean ages of the two groups are in fairly good agreement, there cannot be a complete negation of this effect even by age adjustment. This is not an insignificant factor when dealing with a mathematical model, but since the dissimilarities are of a nature which would tend to decrease the true difference in the two groups, it is felt that this effect will not decrease the statistical significance of the analysis.

3. The eye score relative frequency distribution histograms indicates a bi-modal distribution with a spread of four units for exposed and three units for control. It is stated

that this bi-modal distribution results from the posterior polar category having a different histogram from the other categories so that it has the effect of superimposing a peak at score four on the total relative frequency eye score histogram. Inspection of the other histograms reveals that for both exposed and controlled groups the average score for minute defects is approximately 1½, the average score for opacification is slightly more than 1½, the average score for relucency is slightly more than 1½ and the average score for sutural defects is slightly more than 1. Therefore, the maximum peak score to anticipate by this line of logic is 6 to 7 (the approximate sum total of the average score for minute defects, opacification, relucency and sutural defects).

One must consider the possibility that an unweighted summation of individual lens score categories to form a total score for an individual is inadequate. It should be noted that although the bi-modal distribution of eye score does raise some question regarding the summation procedure, a bi-modal distribution does not necessarily rule out the procedure of taking an unweighted summation of the individual eye score categories. Furthermore, on the basis of available information, this method is the only feasible manner in which to express the data.

4. Exposure score and duration of microwave work are generally similar and it is stated that they should be correlated. Thus the higher the exposure score, the more likely the individual belongs to a chronically exposed portion of the microwave sample. The only sample of a group with high exposure score can be found in Figure 4-8 of RADC-TN-61-226 (6) which contains the graphs of eye score vs. age for a sample of fifty exposed personnel each of whom had an exposure score of more than twenty-five and fifty age-matched controls. It becomes evident that this too is a seemingly contradictory result. Although this finding was not considered to be of much importance statistically, it should not be completely dismissed from consideration.

5. The analysis of the data from the group examined after October, 1961 (i.e., since the last report) is depicted in Figure 4-5-b and it noted that, due to the greater value for the regression coefficient for the exposed group, and the slightly lower mean eye score at the lower ages, these two linear regression graphs intersect with the exposed group showing the greater mean eye score at greater age values. Two ages were chosen to test the difference in mean eye score, the overall mean age of 32.7 years, where the difference was not significant and the projected age of sixty years where the difference of anticipated mean eye score was found to be significant.

However, the finding that the mean eye score at the younger than thirty-two group differed from expected in that the exposed group had lower mean eye scores than the control group was not considered abnormal in this instance because in linear regression analyses such findings are not unexpected since the difference of lower ages is not statistically significant. An analysis of these findings would not be critical if the possibility of an inexact mathematical model selection was not suggested.

6. The total eye score was broken down into its five components and the frequency distributions of each were determined. It was stated that because of limitations of the scoring system (i.e., only four possible scores: 0,1,2,3) for each category that a rigorous statistical analysis of the type used for the total lens score would not be too meaningful in the determination of the significance of these differences. The data was therefore subjected to a chi-square analysis wherein the category posterior polar defects was found to be the group predominantly responsible for differences found between exposed and control groups.

D. A critical evaluation of the slit-lamp examination reveals that no clinical cataract was found (pathology of the lens resulting in reduction of visual acuity). Two individuals of

the exposed group each were found to have a monocular incipient cataract (sub-clinical pathology of a portion of the lens without reduction of visual acuity). In addition, two other exposed individuals were found to have temporary bilateral intumescent lenses (both of them were accidentally exposed to massive amounts of microwave radiation and a question arises as to whether or not they technically belong in this study). In none of these four individuals was any pathology noted in the posterior polar subcapsular cortex.

1. Posterior Polar Defects. The posterior polar defect category requires discussion at this point. By definition, it is a topographical region of the lens situated along the axis at the posterior cortex between the posterior suture and the capsule of the lens. It is a frequent site for pathological change including that due to ionizing radiation. Especially for the latter reason, it was included as a category in the examination. However, no posterior subcapsular cataracts were encountered in this study. In examining this region of the lens, one is inspecting it by looking through the anterior cortex, the adult nucleus, the anterior suture, the fetal nucleus, the posterior suture and the posterior adult nucleus. Each of these structures alters the light beam that is illuminating the posterior cortex

and also affects the refraction of the examiner. If the pathology is present in this region and the intervening lens is clear, it is not difficult to determine the nature and extent of the pathology. However, if no visible pathology is present in the posterior polar cortex, it appears that this is not a reliable site for quantitative analysis.

The other categories of the slit-lamp examination appear to lend themselves to semi-quantitative evaluation.

2. Minute Defects. One of the compelling reasons for instituting this study was to determine whether or not a relationship exists between imperfections such as granules, vacuoles and tiny opacities in the lens and microwave exposure. Examination of the histogram for minute defects and evaluation by means of the chi-square analysis indicates that there is no significant difference between exposed and control groups.

3. Opacification. In any study of cataract formation, it is desirable to attempt to estimate the degree of opacification. By chi-square analysis there was a suggestion that opacification may be an indicator of exposure to microwave radiation. However, examination of the histogram does not unequivocally indicate this to be true. Subsequent to the origin of this study, fortuitous examination of four human lenses (two individuals)

displaying various degrees of microwave cataracts has revealed that the basic pathology takes place in the capsule surrounding the lens and that the capsular pathology reduced the visual acuity years before the lens substance becomes opacified. This finding was so marked that the diseased capsule could be readily identified by direct inspection without the need of magnification and light beam provided by the slit-lamp. However, detailed slit-lamp examinations were performed and years intervened from the time of exposure before any measurable opacification of the lens substance took place in two of these lenses (one from each individual). The other two lenses, at last inspection, still exhibited no opacification of the lens substance in spite of slowly progressing capsular changes.

4. Relucency. As the lens substance itself becomes a secondary luminaire when illuminated by the light beam, this luminescence was examined by estimating the degree of relucency of the light beam in the lens. The assumption was made that changes in relucency might antedate opacification and thus alterations in the degree of relucency might prove to be an indicator of metabolic change in the lens. However, not only has no significant difference between exposed and control groups been elicited but also this test has not been of any value when

applied to the above-mentioned microwave cataracts.

5. <u>Sutural Defects</u>. As mentioned previously, this category was examined on the basis of experimental microwave cataracts. The species difference between the laboratory animals in which this factor is the predominant reaction to microwave exposure and man where this factor has not been found to be related to such exposure has become evident and there is no significant difference between exposed and control groups. Moreover, in human microwave cataracts, at no stage of development has any abnormality of the sutures been noted.

CONCLUSIONS

Analysis of the data reveals that the lenses of both microwave workers and controls have defects and that the number of defects increase linearly with age. Although there was an apparent statistical difference in eye score between the exposed and control groups, the difference is demonstrated to be clinically insignificant. The extent of minor lenticular imperfection does not serve as a clinically useful indicator of cumulative exposure to microwave radiation. No relationship between lens imperfection and microwave cataract was found.

Within the limitations of the sample obtained, of the definition of chronic exposure to permissible levels of microwave radiation, and of the ophthalmological technique employed, this investigation has demonstrated that it is impractical to monitor microwave exposure by means of performing this type of examination at some future time as a follow-up procedure. Even if one were to assume that the mathematical models were perfect and that the mean number of minor lens defects would diverge as predicted by means of the ANALYSIS OF THE FEASIBILITY OF PERIODIC LENS EXAMINATIONS TO MONITOR MICROWAVE EXPOSURE EFFECTS, it is clearly stated beyond a resonable doubt that it is not feasible to continue this study.

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TABLE I-1

INSTALLATION	TYPE	MAJOR FUNCTION(S)
A	large military base (>1000 employees)	a. research and development of surface radar b. airborne radar maintenance
B	civilian assembly plant	a. design and assembly of microwave modulators b. components testing
C	large military missile tracking facility (>1000 employees)	a. radar operations and maintenance b. systems development
D	smaller military missile tracking facility	a. radar operations and maintenance
E	civilian research development and fabrication facility	a. research and development of reconnaissance radar b. tube production facilities c. antenna development work

TABLE I-1 (continued)

F	large civilian radar installation	a. research and development of radar defense systems b. radar equipment operation c. testing of radar equipment
G	civilian research laboratory	a. research and development of military and communications type radar equipment b. fabrication and c. testing of radar equipment d. limited operation of radar equipment
H	civilian fabricator of radar equipment	a. fabrication and b. testing of radar
I	civilian complex of radar operations	a. research and development b. fabrication and c. testing of radar systems

TABLE I-1 (continued)

J	military missile tracking installation	a. operation and maintenance of high powered (i.e., $>$ 1 megawatt) search radar.
K	large military missile tracking facility and air base ($>$1000 employees)	a. operation and maintenance of long range search radar for area surveillance and missile tracking b. operation and maintenance of navigational radar c. systems development
L	large naval vessel	a. operation and maintenance of search and navigational equipment b. airborne radar maintenance
M	large military training and research development center	a. training of radar operators and maintenance personnel b. research and development of military radar c. limited operation of radar equipment

TABLE 3-1

METHOD OF CALCULATING MICROWAVE EXPOSURE INDEX*

Factor	Weight		
	1	2	3
1. Power output (av. watts)	<100	100-1000	>1000
2. Distance from tube or transmission line (feet)	< 10	>10	—
3. Looked into energized waveguide (no. of times)	1-10	—	>10
4. Felt heat from waveguide	< 10	Hands only >10	Head or whole body >1
5. Antenna exposure (location and time)	Rear or sides	Front (sec. or min.)	Front (hours)
6. Antenna heat (time)	Seconds	Minutes	Hour
7. Antenna power (av. watts)	<100	100-1000	>1000

*Exposure Index = (1 x 2 x 3 x 4) + (5 x 6 x 7).

TABLE 4-1

AGE FREQUENCY DISTRIBUTION

	EXPOSED GROUP			CONTROL GROUP		
Age Group	Number of Individuals	%	Cumulative %	Number of Individuals	%	Cumulative %
16-20	45	6.114	6.114	59	10.55	10.55
21-25	126	17.12	23.23	106	18.96	29.51
26-30	186	25.27	48.50	91	16.28	45.79
31-35	137	18.61	67.11	88	15.74	61.53
36-40	103	14.00	81.11	73	13.06	74.59
41-45	60	8.15	89.26	64	11.45	86.04
46-50	33	4.48	93.74	44	7.87	93.91
51-55	25	3.40	97.14	17	3.04	96.95
56-60	19	2.58	99.72	13	2.33	99.28
61-65	2	.28	100.00	4	.72	100.00
	TOTAL 736			TOTAL 559		
	MEAN AGE = 32.76 YEARS			MEAN AGE = 33.20 YEARS		

TABLE 4-2

EYE SCORE FREQUENCY DISTRIBUTION

Total Eye Score	EXPOSED GROUP Number Individuals	%	Cumulative %	CONTROL GROUP Number Individuals	%	Cumulative %
0	0	0	0	0	0	0
1	7	0.95	0.95	5	0.89	0.89
2	14	1.90	2.85	17	3.04	3.93
3	42	5.71	8.56	47	8.41	12.34
4	136	18.48	27.04	100	17.90	30.24
5	84	11.41	38.45	64	11.45	41.69
6	70	9.51	47.96	55	9.84	51.53
7	85	11.55	59.51	93	16.64	68.17
8	126	17.12	76.63	76	13.60	81.77
9	93	12.64	89.27	59	10.55	92.32
10	42	5.71	94.98	23	4.11	96.43
11	18	2.44	97.42	10	1.79	98.22
12	10	1.35	98.77	8	1.43	99.65
13	7	.95	99.72	2	.35	100.00
14	1	.14	99.86	0	0	100.00
15	1	.14	100.00	0	0	100.00
	TOTAL NUMBER = 736 MEAN EYE SCORE 6.58			TOTAL NUMBER = 559 MEAN EYE SCORE 6.23		

TABLE 4-3

EXPOSURE SCORE FREQUENCY DISTRIBUTION

EXPOSURE SCORE	NUMBER EXPOSED	%	CUMULATIVE %
1-5	109	14.81	14.81
6-10	267	36.28	51.09
11-15	133	18.07	69.16
16-20	94	12.77	81.93
21-25	54	7.34	89.27
26-30	24	3.26	92.53
31-35	6	.82	93.35
36-40	12	1.63	94.98
41-45	18	2.45	97.43
46-50	3	0.41	97.84
51-55	2	0.27	98.11
56-60	4	0.54	98.65
61-65	2	0.27	98.92
66-70	4	0.54	99.46
71-75	3	0.41	99.87
76-80	0	0.00	99.87
81-85	1	0.1	100.00

TABLE 4-4

DURATION OF MICROWAVE WORK

DURATION (months)	NUMBER INDIVIDUALS	%	CUMULATIVE %
0-19	147	20.00	20.00
20-39	127	17.28	37.28
40-59	113	15.37	52.65
60-79	89	12.11	64.76
80-99	71	9.66	74.42
100-119	52	7.07	81.49
120-139	50	6.80	88.29
140-159	26	3.54	91.83
160-179	13	1.77	93.60
180-199	14	1.91	95.51
200-219	13	1.77	97.28
220-239	3	.41	97.69
240-259	10	1.36	99.05
260-279	2	0.26	99.31
280-299	3	0.41	99.72
300-319	0	0	99.72
320-339	0	0	99.72
340-359	0	0	99.72
360-379	1	.14	99.86
560-579	1	.14	100.00

etc. Note: one reject

TABLE 4-5

MICROWAVE WORKERS JOB CLASSIFICATION

JOB CLASSIFICATION	NUMBER INDIVIDUALS	%
0	88	12.00
1	9	1.23
2	83	11.31
3	212	28.88
4	2	0.27
5	4	0.54
6	242	32.97
7	14	1.91
8	69	9.40
9	11	1.50

Note: Two rejects

TABLE 4-6

INDIVIDUAL EYE SCORE CATEGORY FREQUENCIES

	INDIVIDUAL CATEGORY EYE SCORE			
	0		1	
Category	Number Exposed	Number Controls	Number Exposed	Number Controls
Minute defect.	14	8	305	258
Opacification	30	44	300	236
Relucency	28	23	304	238
Sutural defects	75	49	469	360
Posterior polar Defects	383	349	257	192
Totals	530	473	1635	1284

	INDIVIDUAL CATEGORY EYE SCORE			
	2		3	
Category	Number Exposed	Number Controls	Number Exposed	Number Controls
Minute defects	337	238	80	55
Opacification	355	252	51	27
Relucency	371	274	33	24
Sutural defects	172	133	20	17
Posterior polar Defects	91	18	5	0
Totals	1326	915	189	123

TABLE 4-6

INDIVIDUAL EYE SCORE CATEGORY FREQUENCIES

	INDIVIDUAL CATEGORY EYE SCORE			
	0		1	
Category	Number Exposed	Number Controls	Number Exposed	Number Controls
Minute defects	14	8	305	258
Opacification	30	44	300	236
Relucency	28	23	304	238
Sutural defects	75	49	469	360
Posterior polar Defects	383	349	257	192
Totals	530	473	1635	1284

	INDIVIDUAL CATEGORY EYE SCORE			
	2		3	
Category	Number Exposed	Number Controls	Number Exposed	Number Controls
Minute defects	337	238	80	55
Opacification	355	252	51	27
Relucency	371	274	33	24
Sutural defects	172	133	20	17
Posterior polar Defects	91	18	5	0
Totals	1326	915	189	123

TABLE 4-7

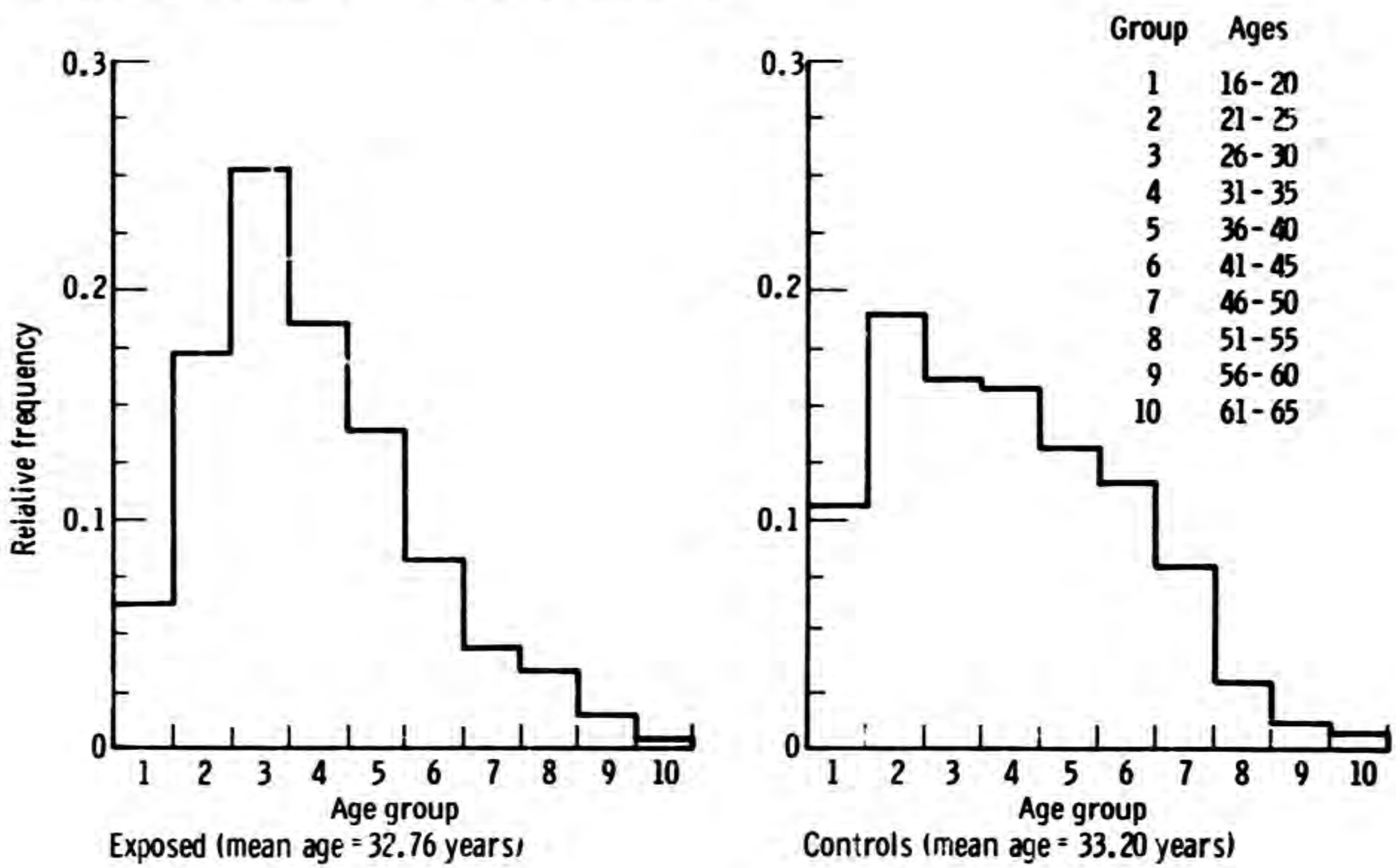
CHI SQUARE VALUES FOR INDIVIDUAL LENS CATEGORIES

Lens Category	Mean Score		Chi Square Value	P Value
	Exposed Group	Control Group		
1. Minute Defects	1.6563	1.6082	2.620	>.05
2. Opacification	1.5802	1.4687	10.244	<.025
3. Relucency	1.5556	1.5349	0.207	>.05
4. Sutural Defects	1.1861	1.2110	1.075	>.05
5. Posterior Polar	0.6168	0.4079	38.540	<.0005

Figure 1-1 Standard Microwave Radiation Hazard Sign

Figure 4-1

RELATIVE FREQUENCY AGE DISTRIBUTION



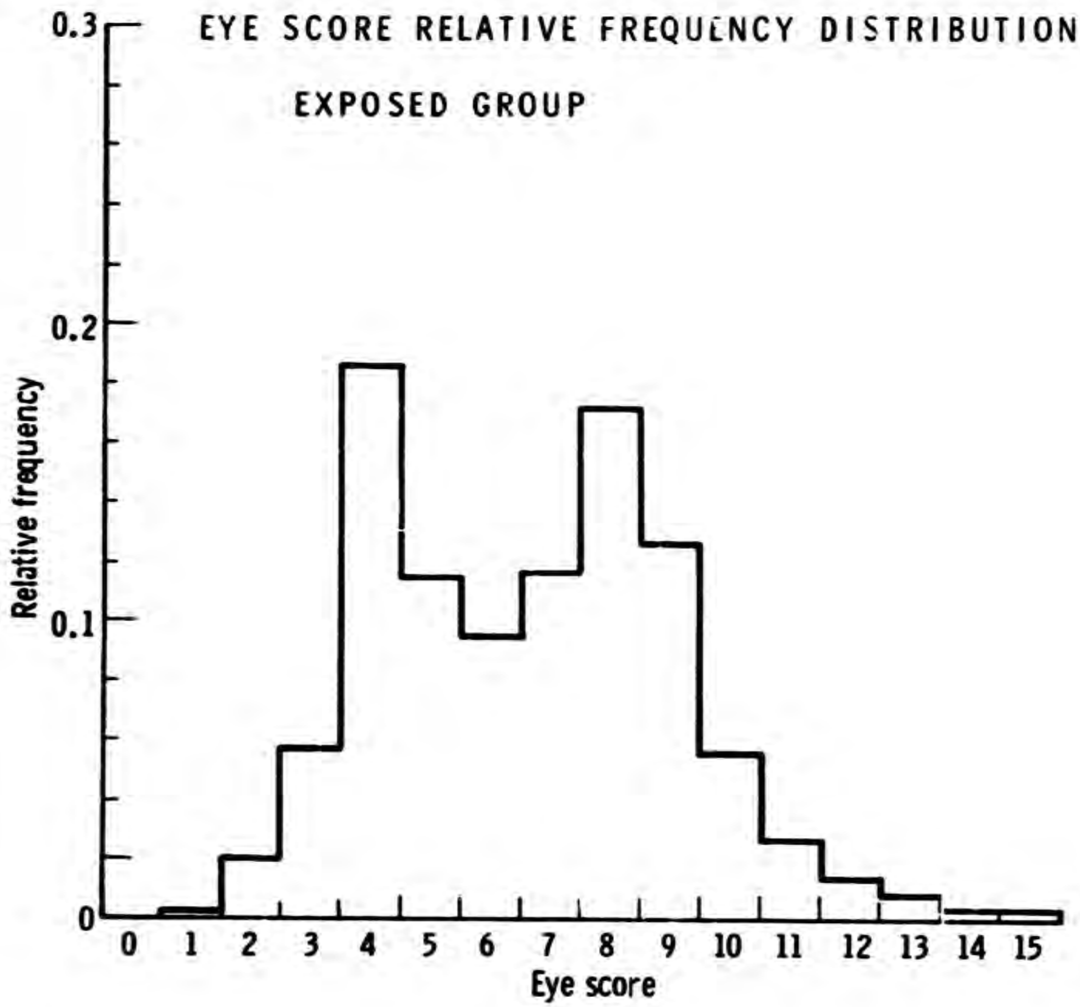
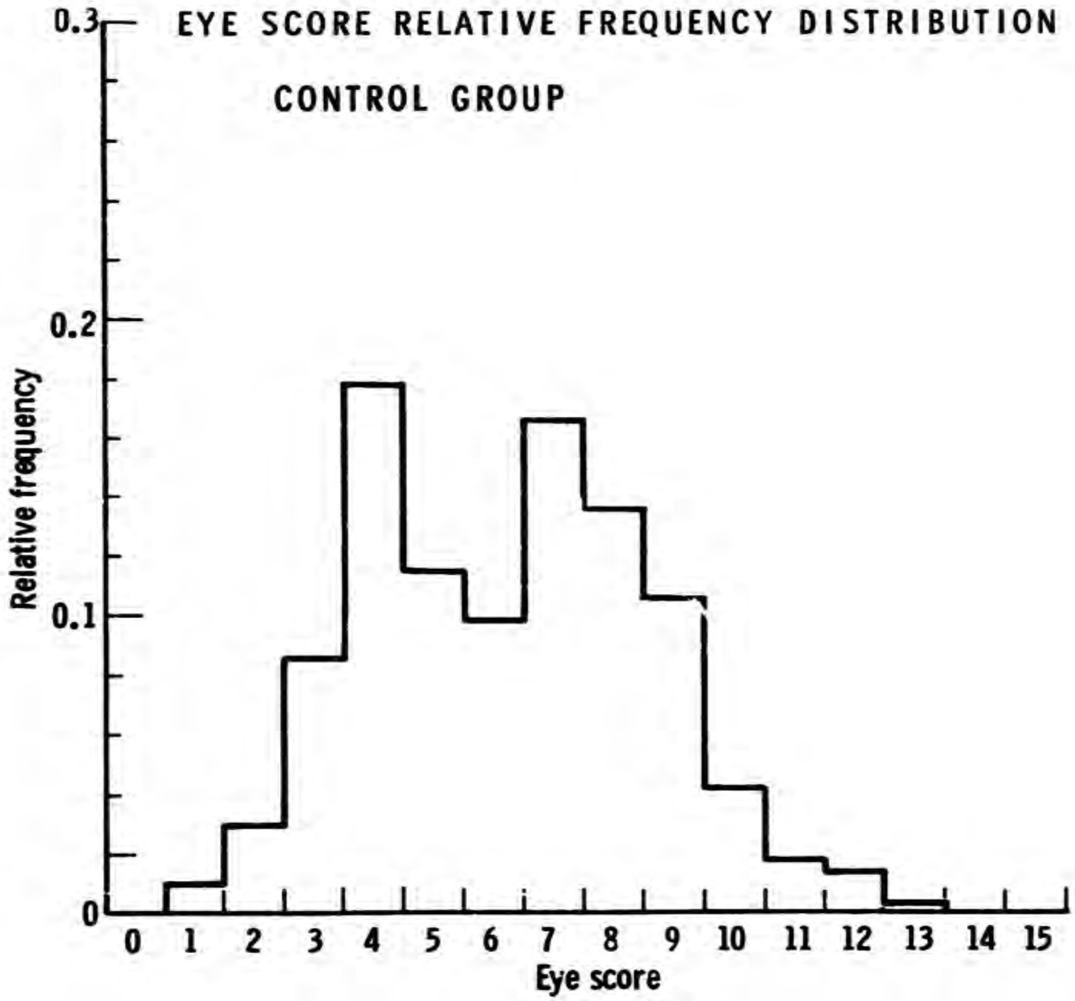

EYE SCORE RELATIVE FREQUENCY DISTRIBUTION
EXPOSED GROUP
0.3
0.2
0.1
0
Relative frequency
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Eye score

Figure 4-2a

Figure 4-2b



EYE SCORE RELATIVE FREQUENCY DISTRIBUTION
CONTROL GROUP
0.3
0.2
0.1
0
Relative frequency
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Eye score

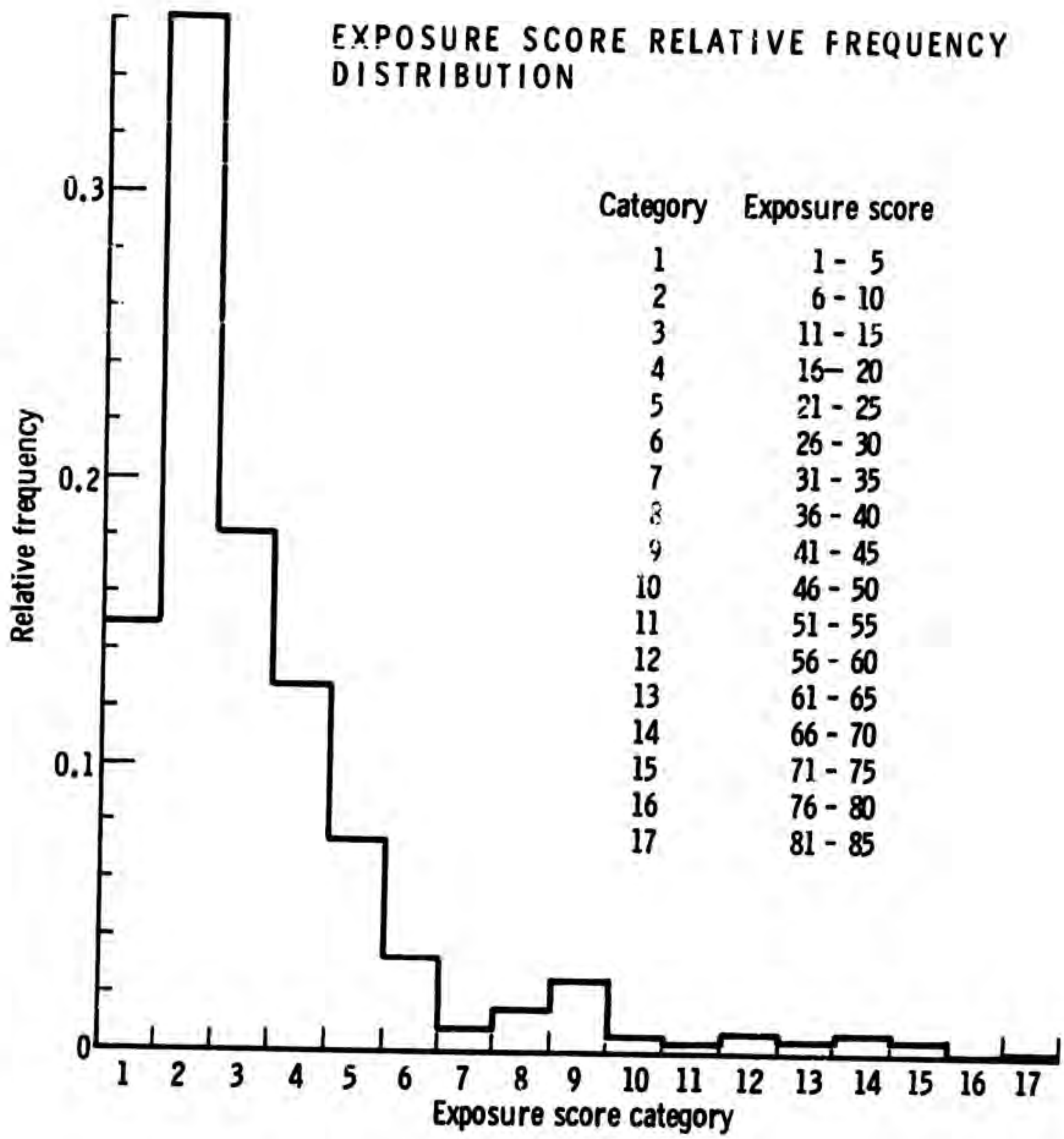
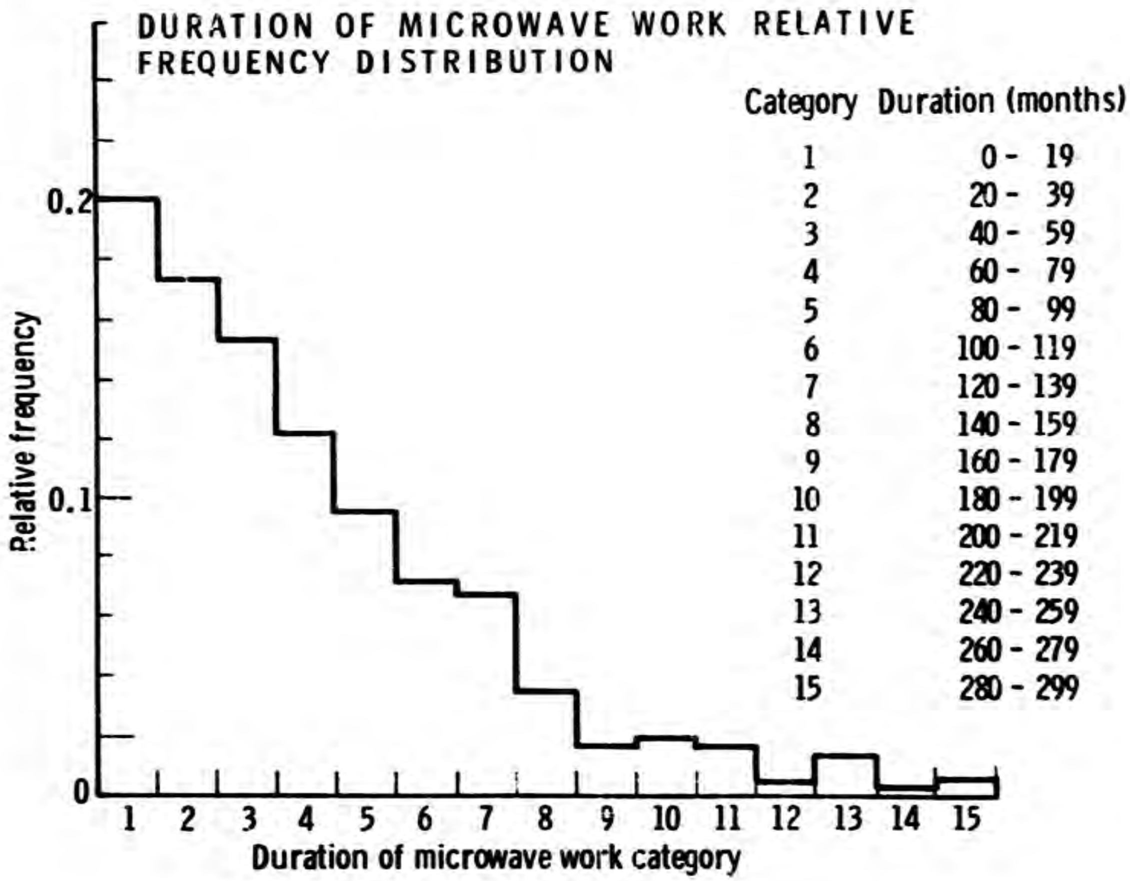
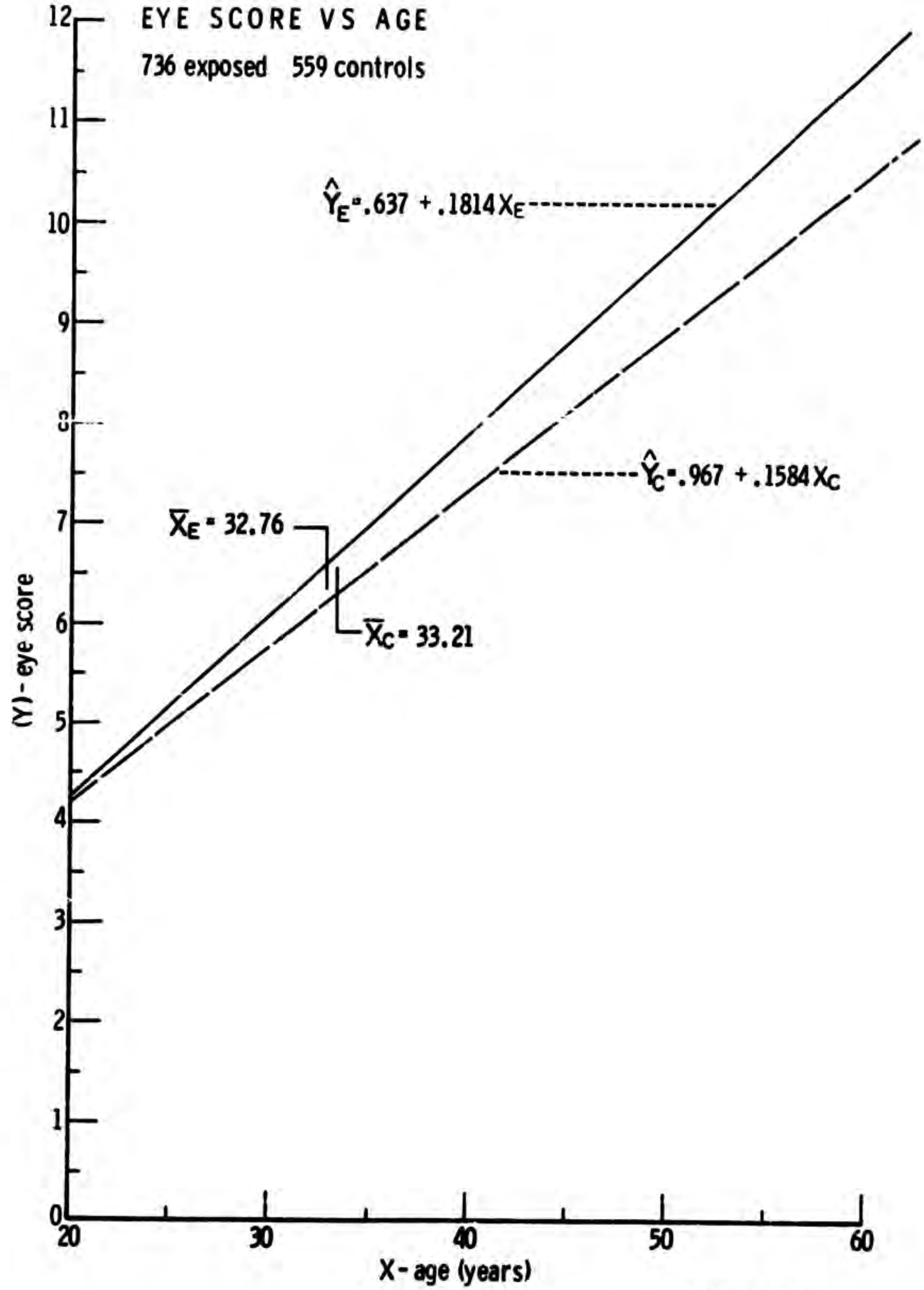

EXPOSURE SCORE RELATIVE FREQUENCY DISTRIBUTION
Category Exposure score
1 1 - 5
2 6 - 10
3 11 - 15
4 16- 20
5 21 - 25
6 26 - 30
7 31 - 35
8 36 - 40
9 41 - 45
10 46 - 50
11 51 - 55
12 56 - 60
13 61 - 65
14 66 - 70
15 71 - 75
16 76 - 80
17 81 - 85
Relative frequency
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Exposure score category

Figure 4-3



DURATION OF MICROWAVE WORK RELATIVE FREQUENCY DISTRIBUTION
Category Duration (months)
1 0 - 19
2 20 - 39
3 40 - 59
4 60 - 79
5 80 - 99
6 100 - 119
7 120 - 139
8 140 - 159
9 160 - 179
10 180 - 199
11 200 - 219
12 220 - 239
13 240 - 259
14 260 - 279
15 280 - 299
Relative frequency
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Duration of microwave work category

Figure 4-4



EYE SCORE VS AGE
736 exposed 559 controls
$\hat{Y}_E = .637 + .1814 X_E$
$\hat{Y}_C = .967 + .1584 X_C$
$\bar{X}_E = 32.76$
$\bar{X}_C = 33.21$
(Y) - eye score
X - age (years)
0
1
2
3
4
5
6
7
8
9
10
11
12
20
30
40
50
60

Figure 4-5a

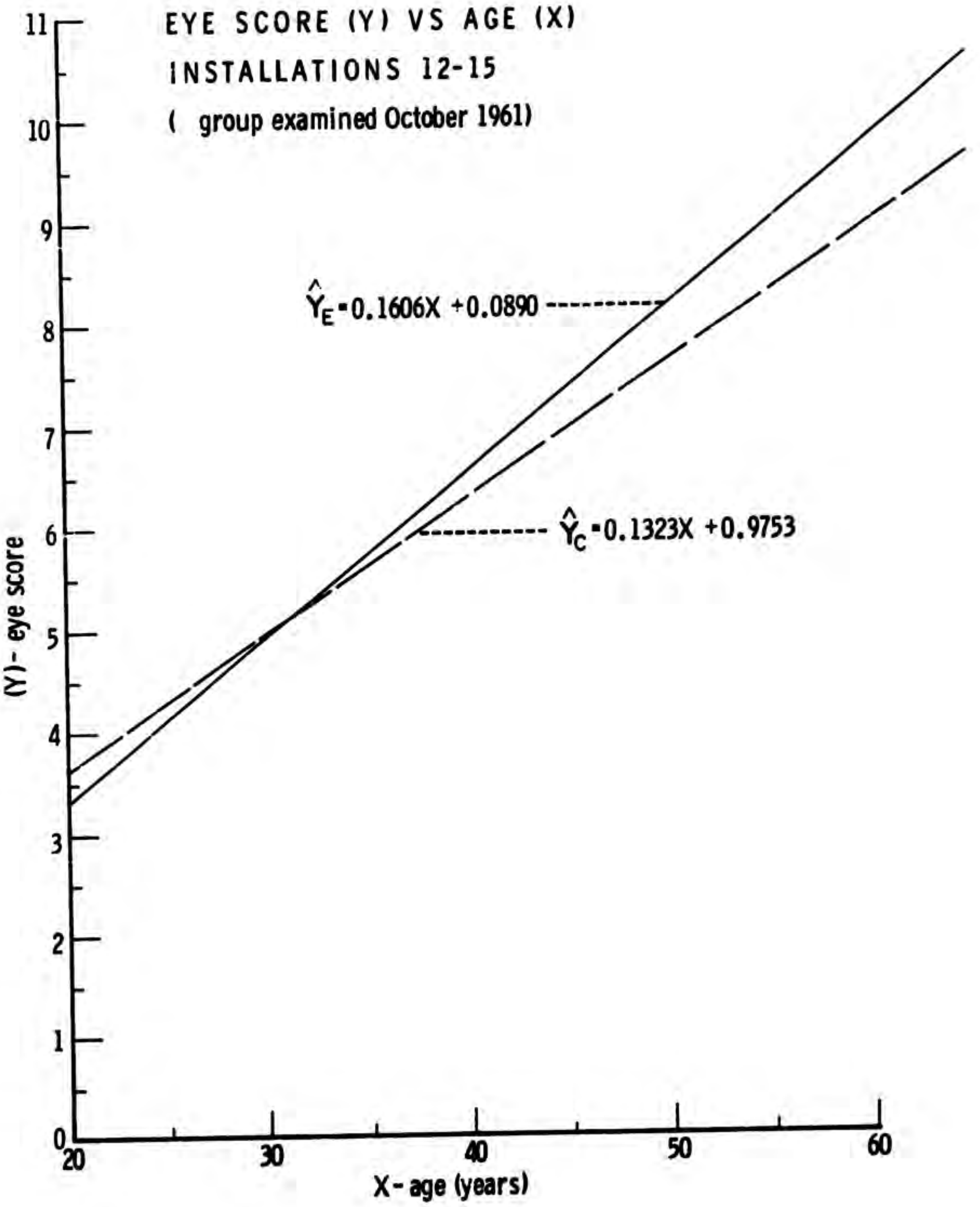
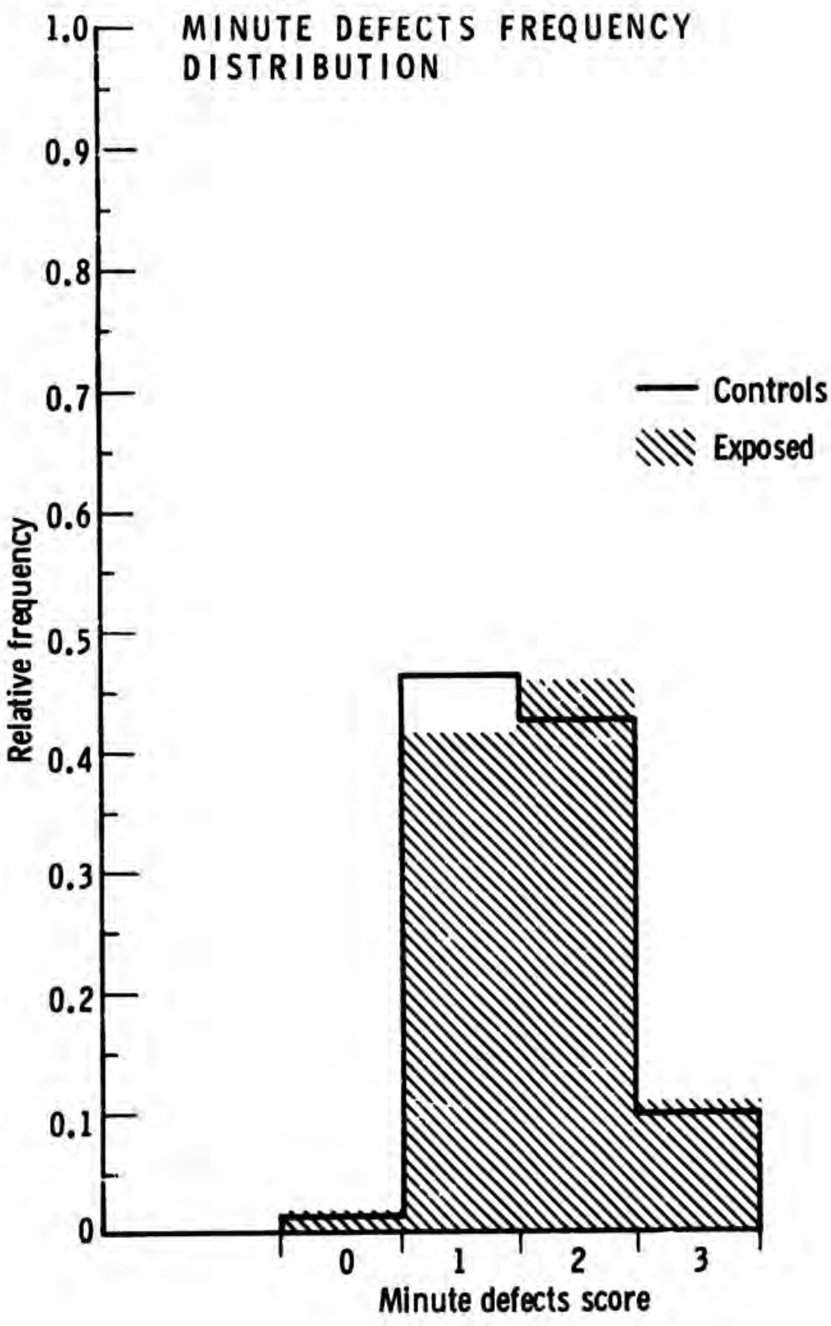

EYE SCORE (Y) VS AGE (X)
INSTALLATIONS 12-15
(group examined October 1961)
$\hat{Y}_E = 0.1606X + 0.0890$
$\hat{Y}_C = 0.1323X + 0.9753$
(Y)- eye score
X- age (years)
0
1
2
3
4
5
6
7
8
9
10
11
20
30
40
50
60

Figure 4-5b



MINUTE DEFECTS FREQUENCY DISTRIBUTION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative frequency
Controls
Exposed
0
1
2
3
Minute defects score

Figure 4-6

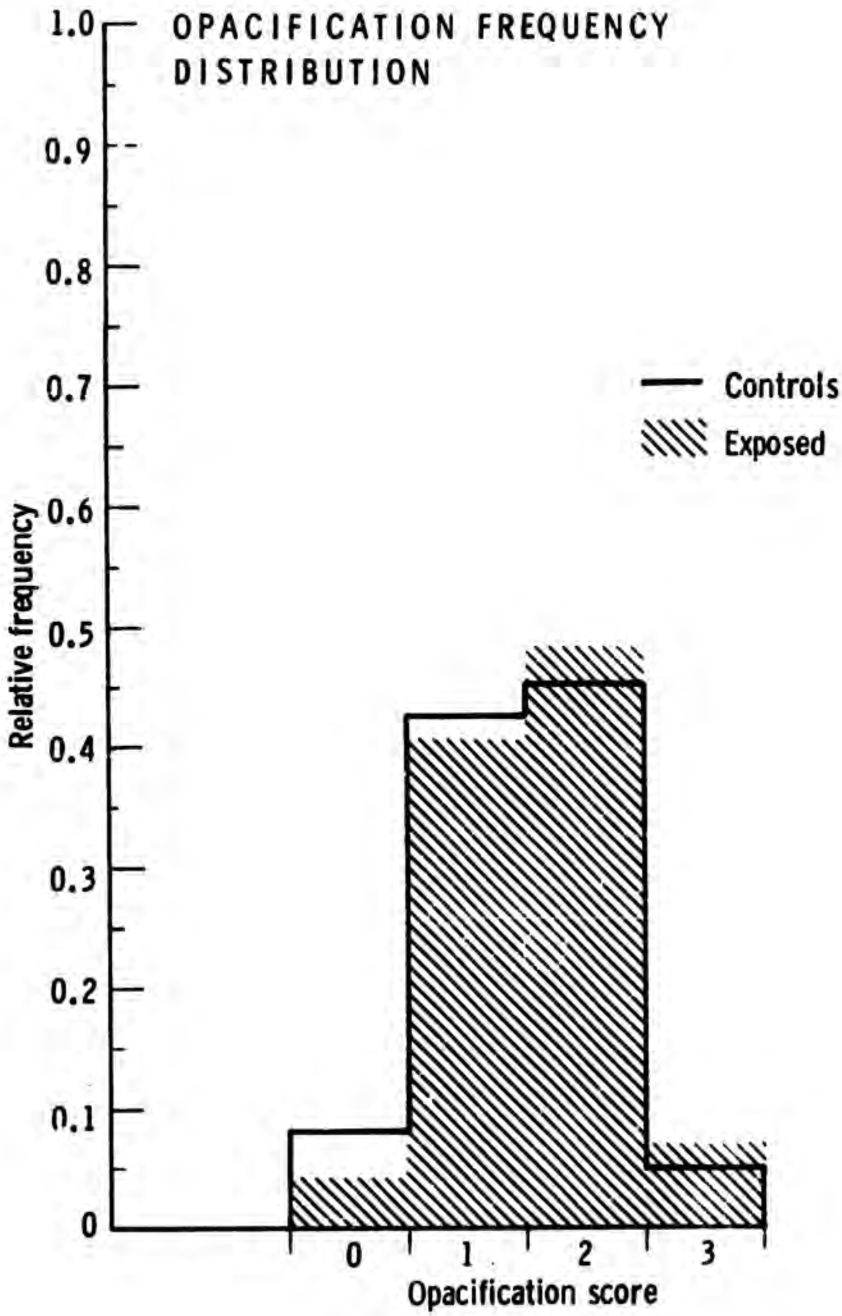
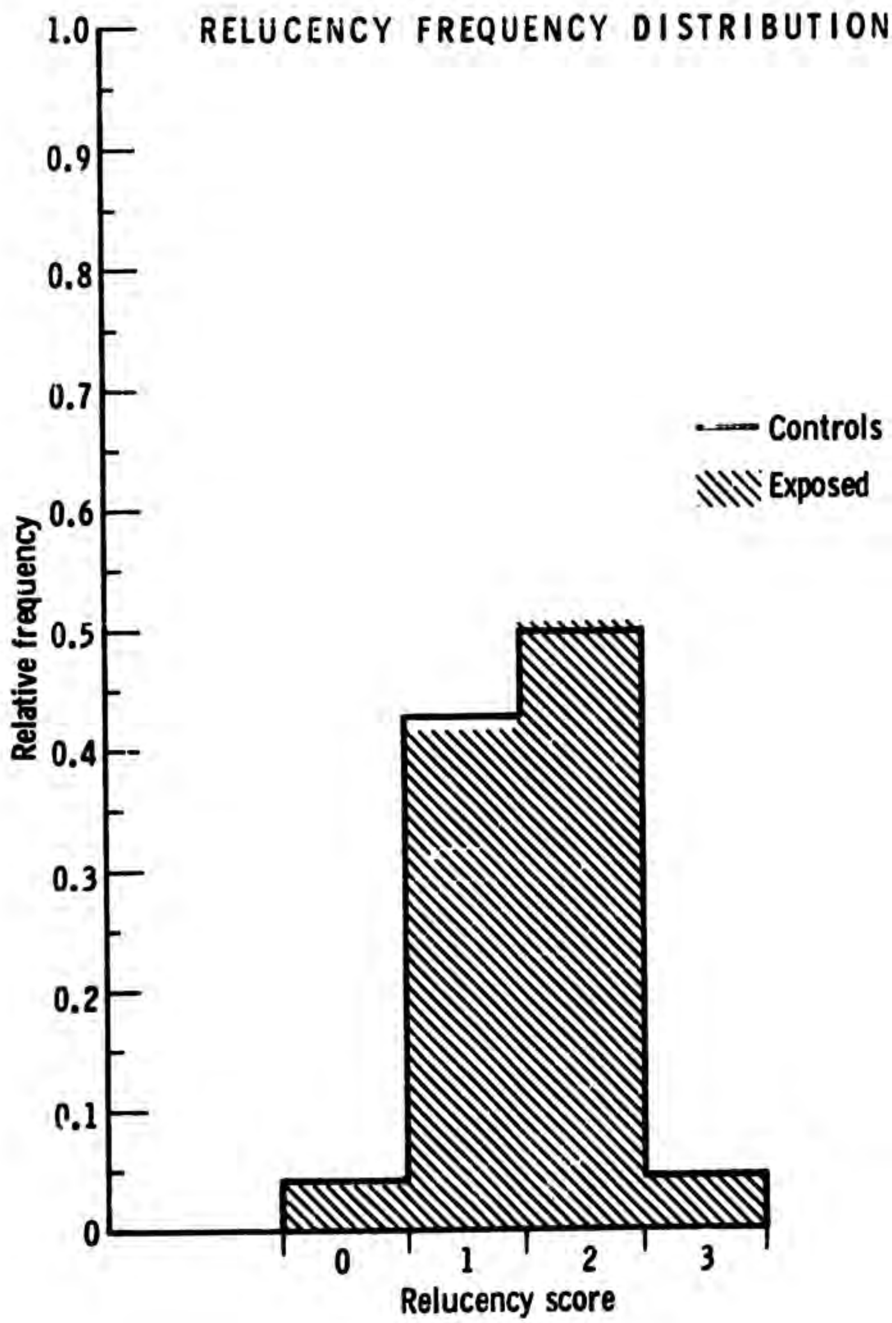

OPACIFICATION FREQUENCY DISTRIBUTION
Relative frequency
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Controls
Exposed
0
1
2
3
Opacification score

Figure 4-7



RELUCENCY FREQUENCY DISTRIBUTION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative frequency
Controls
Exposed
0
1
2
3
Relucency score

Figure 4-8

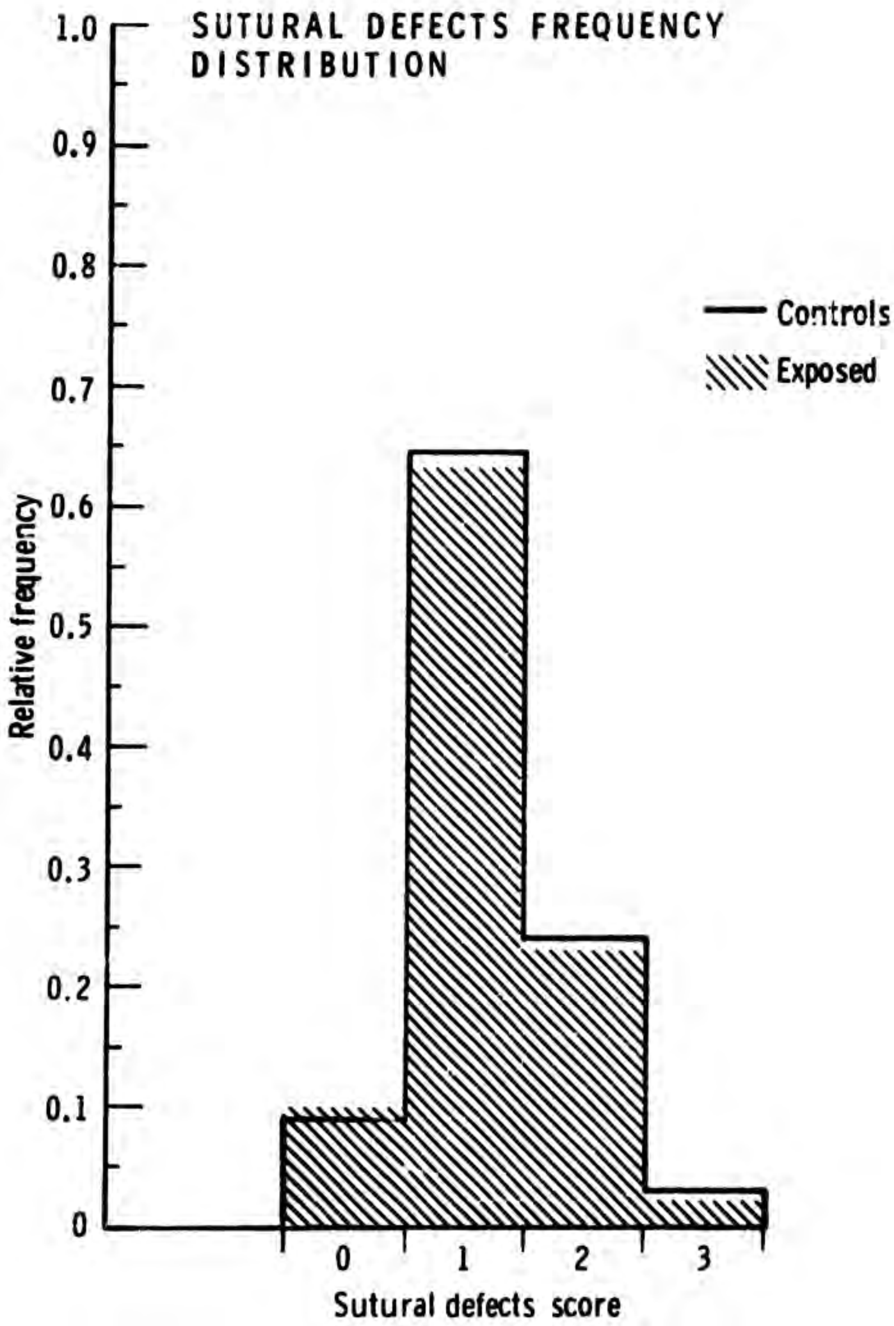
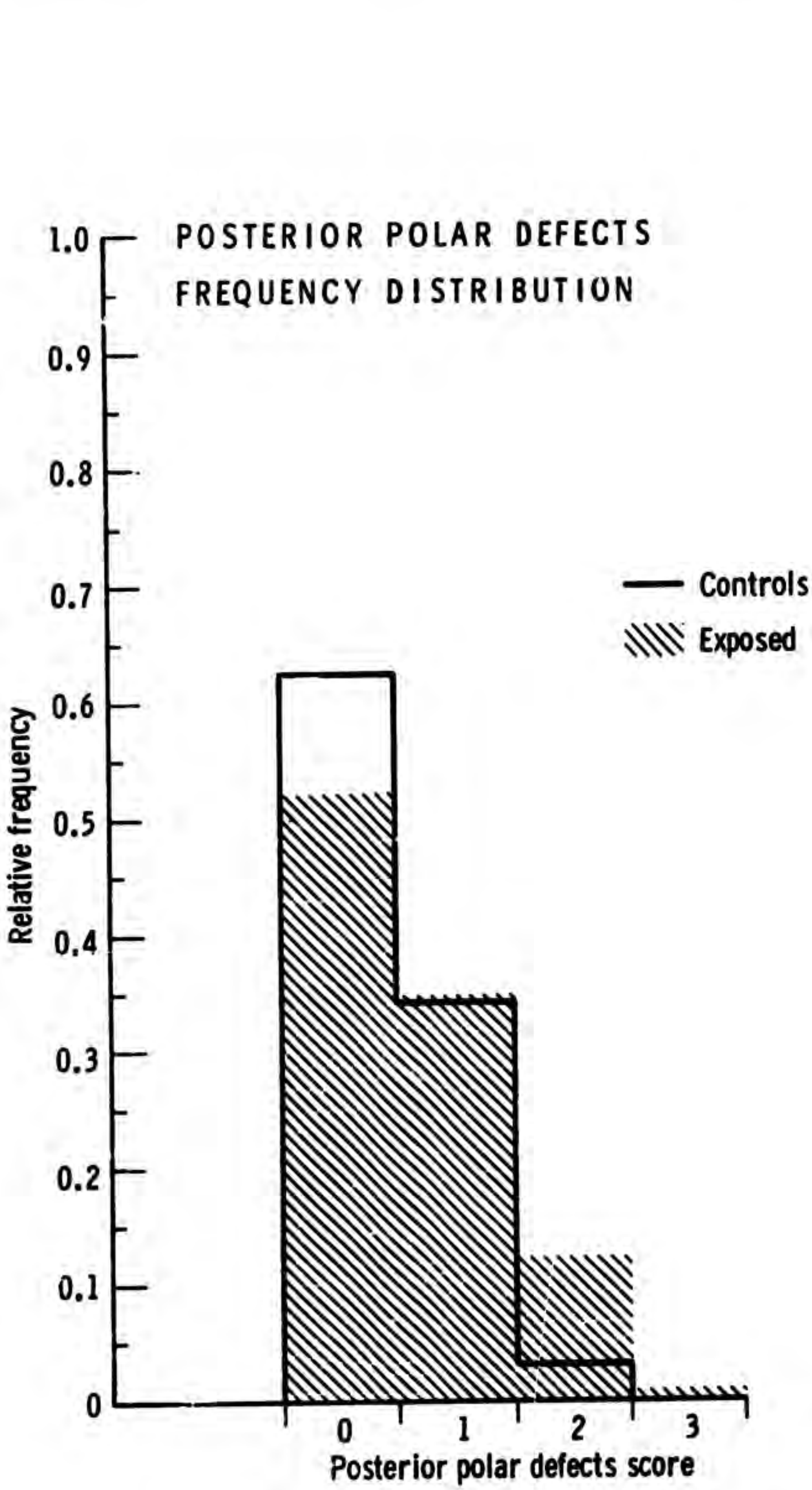
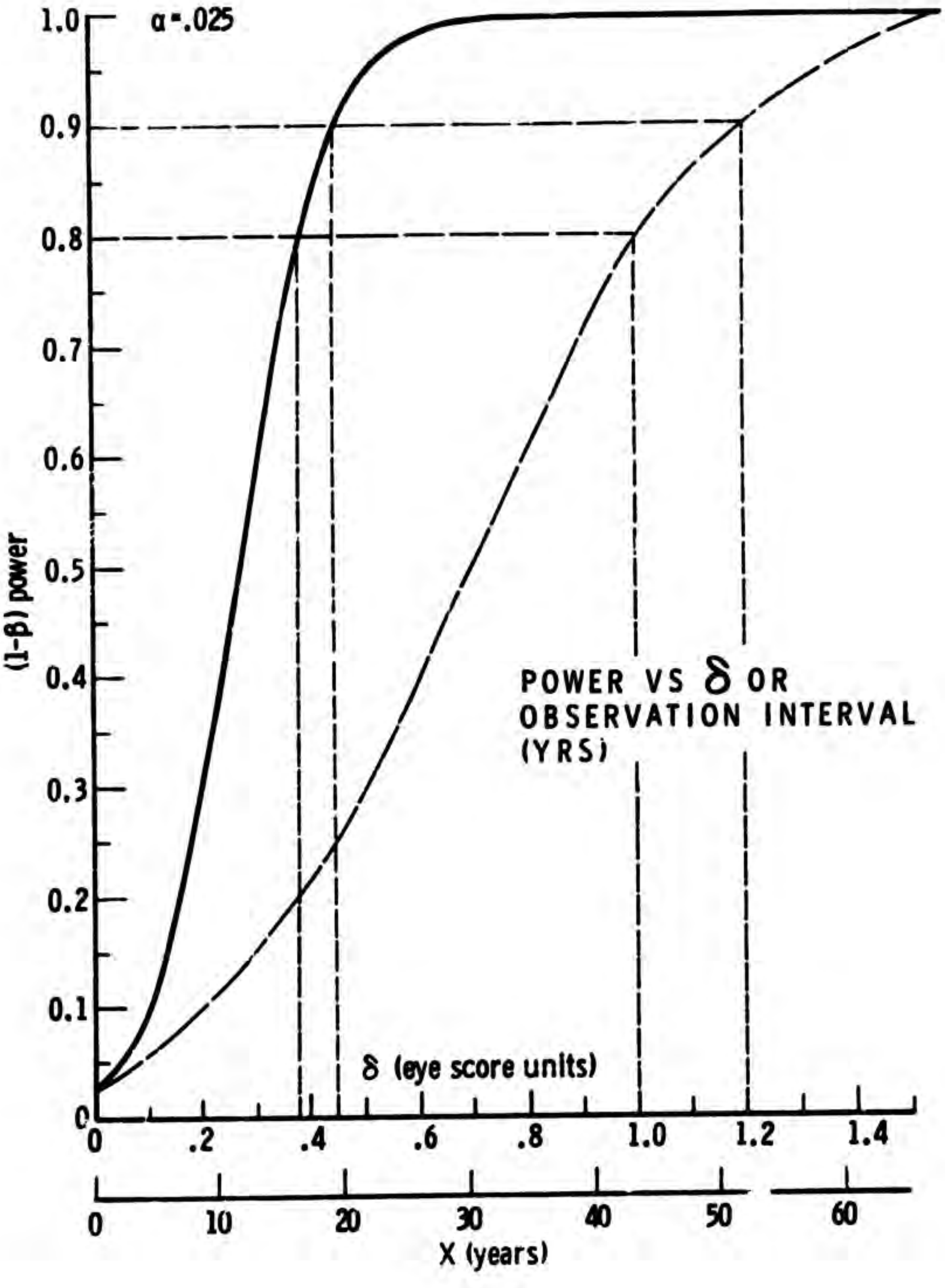

SUTURAL DEFECTS FREQUENCY DISTRIBUTION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative frequency
Controls
Exposed
0
1
2
3
Sutural defects score

Figure 4-9



POSTERIOR POLAR DEFECTS
FREQUENCY DISTRIBUTION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative frequency
Controls
Exposed
0
1
2
3
Posterior polar defects score

Figure 4-10



α = .025
(1-β) power
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
POWER VS δ OR
OBSERVATION INTERVAL
(YRS)
δ (eye score units)
0
.2
.4
.6
.8
1.0
1.2
1.4
0
10
20
30
40
50
60
X (years)

Figure 4-11

APPENDIX III-A

NEW YORK UNIVERSITY MEDICAL CENTER
550 First Avenue
New York 16, New York

Institute of Industrial Medicine
Environmental Radiation Laboratory

HISTORY OF WORK WITH MICROWAVES

You are being asked to fill out this questionnaire as part of a large study in which we are one of a number of participating industrial and military organizations.

We appreciate the fact that in some cases a great many years may have elapsed since you first began to work with microwaves and that it may be difficult for you to recollect all of the detailed information we have asked you to provide. All we request is that you be patient with this questionnaire and fill it out to the best of your ability. If there are any parts of it which are not clear to you, your supervisor will attempt to assist you.

Name______________________________ Age________ Badge No.________
(Please print)

Address___________________________

____

I. List only those places of employment in which you worked with radar or other microwave equipment. List present employer first and work backwards.

a. Employer's Name____________________

Employed from_____to_____

Job Titles: 1.__________

2.__________

3.__________

Total Number of Months Employed in the Following Categories

a. Research and development of microwave components________

b. Microwave components assembly for production____________

c. Operation of radar or other microwave apparatus________

d. Installation, maintenance, and test of microwave apparatus___

e. Other________________

Total________

b. Employer's Name_____________________
Employed from_____to_____
Job Titles: 1.___________
2.___________
3.___________

a. Research and development of microwave components______
b. Microwave components assembly for production____________
c. Operation of radar or other microwave apparatus_______
d. Installation, maintenance, and test of microwave apparatus__________
e. Other________________

Total________

c. Employer's Name_____________________
Employed from____to______
Job Titles: 1.___________
2.___________
3.___________

a. Research and development of microwave components______
b. Microwave components assembly for production____________
c. Operation of radar or other microwave apparatus_______
d. Installation, maintenance, and test of microwave apparatus____
e. Other__________________

Total_______

d. Employer's Name_____________________
Employed from____to______
Job Titles: 1.___________
2.___________
3.___________

a. Research and development of microwave components______
b. Microwave components assembly for production____________
c. Operation of radar or other microwave apparatus_______

d. Installation, maintenance, and test of microwave apparatus__________

e. Other__________

Total__________

II.

a. Did you ever wear a film badge? Yes________ No________

b. If yes, on which job and during what period of time?

Places of Employment	From	To
a.__________	________	________
b.__________	________	________
c.__________	________	________
d.__________	________	________

III.

a. Did you ever work near a transmitter tube from which the shielding was removed while the high voltage was on?
Yes________ No________

b. If yes, fill out the following:

Tube Type	Aver. Power	Peak Voltage	Sec.	Min.	Hrs.	Longer

IV. List the principal types of microwave generating equipment with which you have worked.

	a.	b.	c.	d.
Type of equipment				
Average Power				

Freq. or Band	________	________	________	________
Number of months	________	________	________	________
Date of first exposure	________	________	________	________
Power terminated (use check mark)				
Dummy load	________	________	________	________
Outside antenna	________	________	________	________
Within room	________	________	________	________
Distance from equipment				
Less than 10 ft.	________	________	________	________
10 - 20 ft.	________	________	________	________
Greater than 20 ft.	________	________	________	________
Your work was:				
a. research & development	________	________	________	________
b. assembly of microwave components	________	________	________	________
c. operation of microwave equipment	________	________	________	________
d. Installation, maintenance, and test of microwave equipment	________	________	________	________

V.

a. Did you ever look into a transmission line such as a wave guide while it was energized? Yes________ No________

V-a (Continued)

If yes:

How many times?			Average Power?	How Viewed?	
1-3	4-10	over 10		Viewing Bend	Open Wave Guide
___	___	___	___	___	___
___	___	___	___	___	___
___	___	___	___	___	___
___	___	___	___	___	___

VI.

a. Did you ever feel heat from microwaves coming from a wave guide or transmission line? Yes______ No______

b. If yes, how many times?

	1-3	4-10	Over 10
Hands only	___	___	___
Whole body	___	___	___
Head only	___	___	___

c. What types of equipment were involved?

Average Power	___	___	___
Freq. or Band	___	___	___

VII.

a. Have you ever worked near an antenna while it was radiating? Yes________ No_______

b. If yes, fill in the following:

	1-3	4-10	Over 10	Average Power	Freq. or Band	Distance From Radiating Surface
1.Front Surface						
few seconds	___	___	___	___	___	___
few minutes	___	___	___	___	___	___
over an hour	___	___	___	___	___	___
2.Rear Surface						
few seconds	___	___	___	___	___	___
few minutes	___	___	___	___	___	___
over an hour	___	___	___	___	___	___
3.Sides						
few seconds	___	___	___	___	___	___
few minutes	___	___	___	___	___	___
over an hour	___	___	___	___	___	___

4.How many times did you feel heat from microwaves coming from the antenna?

few seconds	___	___	___
few minutes	___	___	___
over an hour	___	___	___

APPENDIX III-B

EXPLANATORY REMARKS ON

"HISTORY OF WORK WITH MICROWAVES" QUESTIONNAIRE

Part I:

In addition to civilian employment, microwave experience during military duty should be included.

Part III:

This entire question is included to determine if there has been any exposure to ionizing radiation. Therefore, any work done in close proximity to any high voltage tube, even if it was not specifically a microwave transmitter tube, should be included in the answer. Any tube in the kilovoltage range should be specified. The reference to shielding in this question refers to X-ray shielding, not r-f shielding. The term "near" in this question may be defined as within the same room as the unshielded tube.

Part IV:

In specifying the mode of power termination (i.e., dummy load, outside antenna, or within room) for cases a,b,c,d, it would be helpful, if more than one mode of termination was used, to approximate the fraction of the time that each mode was used.

The distance from equipment refers only to the distance during operation of the equipment.

In specifying the job category, when more than one classification applies, the principal one should be used.

When possible (i.e., in case of surveyed exposures) the exact power density and length of exposure should be included. Any exposure other than those occurring as a result of employment should be included; this would apply to home experimentation, etc.

Part V:

Average power is here to be considered as the average power of the transmitter or in the waveguide.

Part VI:

This question refers only to effects of transmitter, transmission lines, and waveguides; it does not refer to antenna exposures which are covered in question VII. If an exposure is reported here as due to local termination of a waveguide with a horn, it should not be reported in the answer to question VII.

Part VII:

Exposure to radiating, rotating antennas should also be included in the answer to this question. In "a" the word near refers to a distance at which the power density is greater than or equal to one milliwatt per square centimeter.

APPENDIX III-C

MICROWAVE SURVEY

Epidemiological Data

Details of Coding Procedure

1. Job Classification (column 18)

In specifying the job classification of an individual in the case where more than one category applies, that category will be chosen which represents twice the period of time spent on any other job listed if the latter is less than six months. If the other jobs listed were worked at for more than six months (each) or were more than one half the period of the major job classification the data will be given another code number signifying combinations of microwave jobs.

Controls will be coded with a 5 signifying non-microwave work.

2. X-Ray Exposure

0 will be used for individuals with no reported work on high voltage tubes and no film badge record.

1 will designate individuals who have worked with unshielded generating tubes of greater than one kilovolt peak voltage for periods of minutes or more with no film badge record of possible exposure.

2 will be used to designate those individuals who note severe exposure to ionizing radiation but did not wear a film badge during the exposure.

3 will designate persons exposed to ionizing radiation while wearing film badges.

3. Power Termination

In any instance in which more than one mode of power termination is used for one power, the most significant mode will be chosen. Thus if power is terminated by a dummy load, an outside antenna and also within the room the latter case will be designated on the card (i.e., by a 2 punch). If both dummy load and outside antenna termination is specified a 3 punch will be used indicating this combination.

4. Age at first exposure will be the age at which the first work with a principal type of microwave generator is listed in the questionnaire.

5. In the case of an individual who has been included as a control but who actually has had some radar experience and does not specify the equipment used, a total score of two will be assigned, to distinguish them from controls.

6. In the event that exposure to microwaves coming from an antenna is listed for two different antennas (different powers and frequencies) the higher powered one will be coded except

where the duration of work on the high powered antenna is specified as being a few seconds and the duration of work on the lower power is hours. In this case the exposure to the lower power will be recorded

Calculation of Approximate Average Power from Peak Power

Average P = (Peak Power) x (Pulse Width) x (Pulse Repetition Rate)

= watts x sec x sec^{-1}

Let P_a = average peak

P_p = peak power

W = pulse width

R = pulse repetition rate

$P_a = P_p WR$

$\frac{P_a}{P_p} = WR$

An average value of WR will be used to convert from peak power to average power

Assume:

$W \doteq 1.0\ \mu sec$

$R \doteq 10^3\ sec^{-1}$

therefore,

$$\frac{P_a}{P_p} \doteq WR \doteq (10^{-6} \times 10^3) = 10^{-3}$$

$$P_a \doteq \frac{P_p}{1000}$$

IBM - Card Layout - Microwave Data

		Col.			
		40 41	AGE AT FIRST EXPOSURE (YEARS)		
		[illegible]	# OF TIMES	LOOKED INTO WAVEGUIDE	
		[illegible]	AVG. POWER		
		[illegible]	NON VIEWER		
		45	HANDS	FELT HEAT FROM GENERATING EQUIPMENT	
		46	BODY		
		47	HEAD		
		48	FREQ.		
		[illegible]	DURATION	FRONT	ANTENNA WORK
		[illegible]	POWER		
		[illegible]	FREQ.		
		[illegible]	DISTANCE		
		[illegible]	DURATION	REAR	
		[illegible]	POWER		
		[illegible]	FREQ.		
		[illegible]	DISTANCE		
		[illegible]	DURATION	SIDES	
		[illegible]	POWER		
		[illegible]	FREQ.		
		[illegible]	DISTANCE		
		[illegible]	ANTENNA HEAT		
		62 63	TOTAL EXPOSURE SCORE		
		[illegible]	EYE DISEASE HISTORY		
		[illegible]	CHANGE OF GLASSES		
		[illegible]	EYE DEFECTS		
		[illegible]	LEFT	VISUAL ACUITY	
		[illegible]	RIGHT		
		[illegible]	MINUTE DEFECTS		LENTICU-LAR CHANGES
		[illegible]	OPACIFICATION		
		[illegible]	RELUCENCY		
		[illegible]	SUTURAL DEFECTS		
		[illegible]	POSTERIOR POLE PHOTO. FINDINGS		
		75 76	SUMMATION OF EYE FINDINGS		
		77 78 79 80			

11	12	Col.			
		1 2	SITE IDENTIFICATION		
		3 4 5 6	INDIVIDUAL IDENTIFICATION		
		7 8	AGE OF INDIVIDUAL (YEARS)		
		9 10	MONTH	DATE OF EYE EXAMINATION	
		11 12	DAY		
		13 14	YEAR		
		15 16 17	DURATION OF MICROWAVE WORK (MONTHS)		
		18	JOB CLASSIFICATION		
		19	X-RAY EXPOSURE		
		20	MONTHS	0-10	AVERAGE POWER OUTPUT OF MICRO-WAVE GENERATOR (WATTS)
		21	FREQ.		
		22	TERM.		
		[illegible]	DIST.		
		[illegible]	JOB		
		[illegible]	MONTHS	11-100	
		[illegible]	FREQ		
		[illegible]	TERM.		
		[illegible]	DIST.		
		[illegible]	JOB		
		[illegible]	MONTHS	101-1000	
		[illegible]	FREQ		
		[illegible]	TERM		
		[illegible]	DIST.		
		[illegible]	JOB		
		[illegible]	MONTHS	>1000	
		[illegible]	FREQ.		
		[illegible]	TERM.		
		[illegible]	DIST.		
		[illegible]	JOB		

MICROWAVE SURVEY IBM CARD CODE DESIGNATION

APPENDIX III-D

Column Number	Field
1-2	<u>Site Identification</u>
	0 - Rome Air Development Command, Rome, New York
	1 - RCA, BEMEWS, Greenland
	2 - Sperry Rand Company, Lake Success, New York
	3 - DuPont, Wilmington, Delaware
	4 - Sylvania, Waltham, Massachusetts
	5 - Pacific Missile Range, Point Mugu
	6 - Pacific Missile Range, Point Arguello
	7 - Sylvania, Mountainview, California
	8 - RCA, Moorestown, New Jersey
	9 - A.T. & T., Bell Labs., Whippany, New Jersey
	10 - Western Electric, Winston Salem, North Carolina
	11 - Raytheon, Waltham, Massachusetts
	12 - RCA, BEMEWS, Clear, Alaska
	13 - USS Franklin D. Roosevelt, New York
	14 - Cape Canaveral, Florida
	15 - Fort Monmouth, New Jersey
3-6	<u>Individual Identification</u>
	Each individual that has been examined will be assigned a number which he will keep throughout

Column Number	Field
	the survey regardless of the site at which he is located. A master sheet will be kept to relate the number to the individual.
7-8	Age of Individual
9-14	Date of Eye Examination Month - columns 9-10 Day - columns 11-12 Year - columns 13-14
15-17	Number of Months of Microwave Work Approximate total months - 0-999 months
18	Job Classification 0 - research and development 1 - assembly of microwave components 2 - operation of radar equipment 3 - installation, maintenance 4 - research and development plus operation of radar equipment 5 - non-microwave work 6 - operation of microwave equipment plus installation, maintenance and test

Column Number	Field
	7 - research and development plus installation, maintenance and test of radar equipment
	8 - combination of job classifications
19	X-Ray Exposure
	0 - no known exposure
	1 - possible exposure
	2 - severe exposure
	3 - film badge worn
20-39	Average Power Output of Microwave Generators
	columns 20-24 - 0-10W data
	columns 25-29 - 11-100W data
	columns 30-34 - 101-1000W data
	columns 35-39 - greater than 1000W data
	columns 20, 25, 30, 35 - approximate duration of microwave work at the specified average power levels (i.e., 0-10W, 11-100W, 101-1000W 10000W)

Column Number	Field
	0 - 0 to 2 months
	1 - 3 to 4 months
	2 - 5 to 8 months
	3 - 9 to 16 months
	4 - 17 to 32 months
	5 - 33 to 64 months
	6 - 65 to 128 months
	7 - 129 to 256 months
	8 - 257 to 512 months
	9 - 513 to 1024 months
	columns 21, 26, 31, 36 - approximate frequency band for specified power levels
	0 - 1 + s bands (1 to 4 kmc/sec)
	1 - c band (4 to 6 kmc/sec)
	2 - x band (5 to 20 kmc/sec)
	3 - k band (18 to 37 kmc/sec)
	4 - q + v band (37 to 57 kmc/sec)
	5 - w band (57 to 100 kmc/sec)
	6 - greater than 100 kmc/sec)
	7 - 0 to 1 kmc/sec
	8 - 1 + s + c + x band combinations
	9 - other combinations of the above bands

Column Number	Field
	columns 22, 27, 32, 27 - mode of power termination at indicated power level 0 - dummy load 1 - outside antenna 2 - within room 3 - combination of dummy load and outside antenna
	columns 23, 28, 33, 38 - distance from microwave generating equipment during operation at the specified power levels 0 - 0 to 10 feet 1 - 11 to 20 feet 2 - greater than 20 feet
	columns 24, 29, 34, 39 - job designation while working with the microwave generator at the indicated power levels. 0 - research and development 1 - assembly of microwave components 2 - operation of radar equipment 3 - installation, maintenance and test

Column Number	Field
	4 - research and development plus operation of radar equipment
	5 - non-microwave work
	6 - operation of microwave equipment plus installation, maintenance and test
	7 - research and development plus installation, maintenance and test of radar equipment
	8 - combinations of job classifications
	9 - research and development plus operation of microwave equipment
40-41	<u>Age of Individual at First Indicated Microwave Work</u>
	0-99 years
42-44	<u>Looked Into Energized Waveguide</u>
	column 42 - number of times individual indicated he looked in energized waveguide
	0 - 1 to 3 times
	1 - 4 to 10 times
	2 - greater than 10 times

Column Number	Field
	column 43 - average power being generated at the time of viewing 0 - 0-10 watts 1 - 11-100 watts 2 - 101-1000 watts 3 - greater than 1000 watts 4 - combination from 0 to 1000 watts column 44 - method of viewing the waveguide 0 - viewing bend 1 - viewing open waveguide 2 - other viewing method 3 - combination of viewing bend and viewing open waveguide 4 - viewing feedhorn (no antenna)
45-48	<u>Felt Heat From Microwave Generator</u> Column 45 - hands only 0 - 1 to 3 times 1 - 4 to 10 times 2 greater than 10 times

Column Number	Field
	column 46 - whole body
	0 - 1 to 3 times
	1 - 4 to 10 times
	2 - greater than 10 times
	column 47 - head only
	0 - 1 to 3 times
	1 - 4 to 10 times
	2 - greater than 10 times
	column 48 - frequency band being generated which resulted in the indicated perception of heat
	0 - 1 + s bands (1 to 4 kmc/sec)
	1 - c band (4 to 6 kmc/sec)
	2 - x band (5 to 20 kmc/sec)
	3 - k band (18 to 37 kmc/sec)
	4 - q + v band (37 to 57 kmc/sec)
	5 - w band (57 to 100 kmc/sec)
	6 - greater than 100 kmc/sec)
	7 - 0 to 1 kmc/sec
	8 - 1 + s + c + x band combinations
	9 - other combinations of the above bands

Column Number	Field
49-60	Antenna Work

antenna locations

columns 49-52 - work data in front of antenna

columns 53-56 - work data in rear of antenna

columns 57-60 - work data at side of antenna

columns 49, 53, 57 - duration of work at specified antenna locations while antenna was radiating

0 - seconds

1 - minutes

2 - greater than an hour

columns 50, 54, 58 - antenna power output during work at specified antenna locations

0 - 0 to 100 watts (average power)

1 - 101 to 1000 watts (average power)

2 - greater than 1000 watts (average power)

columns 51, 55, 59 - microwave frequency during work at indicated locations

0 - 1 + s bands (1 to 4 kmc/sec)

1 - c band (4 to 6 kmc/sec)

2 - x band (5 to 20 kmc/sec)

Column Number	Field
	3 - k band (18 to 37 kmc/sec)
	4 - q + v band (37 to 57 kmc/sec)
	5 - w band (57 to 100 kmc/sec)
	6 - greater than 100 kmc/sec)
	7 - 0 to 1 kmc/sec
	8 - 1 + s + c + x band combinations
	9 - other combinations of the above bands
	columns 52, 56, 60 - distance from radiating antenna at indicated antenna locations
	0 - 0 to 10 feet
	1 - 11 to 20 feet
	2 - 21 to 100 feet
	3 - greater than 100 feet
61	Antenna Heat
	column 61 - period during which heat was perceived by the individual working near radiating antennas
	0 - seconds
	1 - minutes
	2 - hours

Column Number	Field
62-63	Exposure Scores
	columns 62-63 - total exposure score
64	Family History of Eye Disease
	0 - mother
	1 - father
	2 - children
	3 - maternal grandmother
	4 - maternal grandfather
	5 - paternal grandmother
	6 - paternal grandfather
	7 - combinations of above
65	Change of Distance Glasses in the Past 10 Years
	0 - x
	1 - 1
	2 - 2
	3 - 3
	4 - 4
	5 - 5
	6 - 6
	7 - 7

Column Number	Field
	8 - 8
	9 - 9 or more
66	Evidence of Eye Defects or Illnesses
	0 - glaucoma
	1 - cataract
	2 - uveitis (iritis, cyclitis, choroiditis)
	3 - retinal detachment
	4 - congenital defects
	5 - keratitis
	6 - ptyrigium (growth on eyelid)
	7 - combinations of the above
	8 - acute symptoms of exposure
67-68	Vision

Right Eye	Left Eye
0 - 20/20	0 - 20/20
1 - 20/30	1 - 20/30
2 - 20/40	2 - 20/40
3 - 20/50	3 - 20/50
4 - 20/70	4 - 20/70
5 - 20/100	5 - 2/100

Column Number	Field	
	6 - 20/200	6 - 20/200
	7 - 20/200	7 - 20/200
69-74	Lenticular Changes	
	69 - minute defects	
	70 - opacification	
	71 - relucency	
	72 - sutural defects	
	73 - posterior polar defects	
	74 - photographic findings	
	0 - insignificant	
	1 - minor	
	2 - moderate	
	3 - major	
75-76	Summation of Lens Defects = 69 + 70 + 71 + 72 + 73	
	00 - 0	07 - 7
	01 - 1	08 - 8
	02 - 2	09 - 9
	03 - 3	10 - 10
	04 - 4	11 - 11
	05 - 5	12 - 12 etc.
	06 - 6	

APPENDIX IV-A TEST OF THE SIGNIFICANCE OF THE DIFFERENCE IN REGRESSION COEFFICIENTS (i.e., β_1's)

The hypothesis $\beta_{1e} = \beta_{1c}$ was tested to determine the statistical significance of the difference in the computed regression coefficients. The analysis was performed as follows:

Ho: $\beta_{1e} = \beta_{1c}$

Ha: $\beta_{1e} \neq \beta_{1c}$.

The statistic

$$F^* = \frac{(b1e-b1e)^2}{s^2p\left[\frac{1}{SXX_e} + \frac{1}{SXX_c}\right]}$$

will follow an F distribution with one and (N_e+N_c-4) degrees of freedom if the hypothesis Ho is true, where

s^2p = pooled estimate of the variance

$$= \frac{SSE_c+SSE_e}{N_e+N_c-4} = 3.1198$$

SSE_c = sum of squares due to error for control group

SSE_e = sum of squares due to error for exposed group

Substituting the values in the expression for F* results in F* = 5.3637, and by referring to the tabulated F values, it can be determined that

$$0.01 < P\left\{ F(1,1291) > F^*(=5.36) \right\} < 0.025.$$

Therefore, the observed difference in the two regression coefficients can be said to be statistically significant.

APPENDIX IV-B TEST OF THE SIGNIFICANCE OF THE DIFFERENCE IN MEAN EYE SCORE

To determine the significance of the difference in eye score at a specific age, the hypothesis $\mu_e = \mu_c$ was tested as follows:

Ho: $\mu_e = \mu_c$

Ha: $\mu_e \neq \mu_c$.

The statistic

$$F^* = \frac{(\hat{Y}_e - \hat{Y}_c)^2}{s^2_p \left[\frac{1}{N_e} + \frac{1}{N_c} + \frac{(X_e - \bar{X}_e)^2}{SXX_e} + \frac{(X_c - \bar{X}_c)^2}{SXX_c} \right]}$$

will follow an F distribution with one and $(N_c + N_e - 4)$ degrees of freedom if Ho is true. Since $\bar{X}_e \doteq \bar{X}_c \doteq 33$, the hypothesis may be tested at the approximate mean age of 33, in which case the above statistic reduces to

$$F^* = \frac{(\hat{Y}_e - \hat{Y}_c)^2 N_e N_c}{s^2_p \ (N_e + N_c)}$$

Substitution results in $F^* = 12.56$ and from the tabulated values of the F distribution, we may determine that

$$P \left\{ F(1,1291) > F^* \ (=12.56) \right\} < 0.0005.$$

Thus, the observed difference in mean eye scores at the approximate mean age of 33, for the groups, can be said to be statistically highly significant.

APPENDIX IV-C TEST OF THE SIGNIFICANCE OF THE DIFFERENCE IN REGRESSION COEFFICIENTS (i.e., β's) OF GROUP TWO (i.e., GROUP SINCE OCT. 1961)

The hypothesis $\beta_{1e} = \beta_{1c}$ was tested to determine the statistical significance of the difference in the computed regression coefficients. The analysis was performed as follows:

Ho: $\beta_{1e} = \beta_{1c}$

Ha: $\beta_{1e} \neq \beta_{1c}$

The statistic

$$F^* = \frac{(b_{1e}-b_{1c})^2}{s^2{}_p\left[\frac{1}{SXX_c} + \frac{1}{SXX_e}\right]}$$

will follow an F distribution with one and (N_e+N_c-4) degrees of freedom if the hypothesis Ho is true, where

$s^2{}_p$ = pooled estimate of the variance

$= \frac{SSE_c+SSE_e}{N_e+N_c-4} = 2.1755$

SSE_c = sum of squares due to error for control group

SSE_e = sum of squares due to error for exposed group

Substituting the values in the expression for F^* results in $F^* = 3.9658$, and by referring to the tabulated F values, it may be determined that

$$P\left\{F(1,453) > F^*(=3.9658)\right\} < 0.05.$$

Therefore, the observed difference in the two regression coefficients can be said to be statistically significant.

APPENDIX IV-D TEST OF THE SIGNIFICANCE OF THE

DIFFERENCE IN MEAN EYE SCORE OF GROUP TWO
(i.e., GROUP EXAMINAED AFTER OCT. 1961)

To determine the significance of the difference in eye score at a specific age, the hypothesis $\mu_e = \mu_c$ was tested as follows:

Ho: $\mu_e = \mu_c$

Ha: $\mu_e \neq \mu_c$.

The statistic

$$F^* = \frac{(\hat{Y}_e-\hat{Y}_c)^2}{s^2_p \left[\frac{1}{N_e} + \frac{1}{N_c} + \frac{(X_e-\overline{X}_e)^2}{SXX_e} + \frac{(X_c-\overline{X}_c)^2}{SXX_c}\right]}$$

will follow an F distribution with one and (N_e+N_c-4) degrees of freedom if Ho is true.

1) The hypothesis Ho was tested first at the overall mean age for the combined group (i.e., $X_e = X_c = 32.7133$).

The following values were determined for substitution in the above equation:

$\hat{Y}_e = 5.3427$

$\hat{Y}_c = 5.3033$

$s^2_p = 2.1755$

$N_c = 261$

$N_c = 196$

$\overline{X}_e = 31.5096$

APPENDIX IV-E

ANALYSIS OF THE FEASIBILITY OF PERIODIC LENS EXAMINATIONS TO MONITOR MICROWAVE EXPOSURE EFFECTS

The difference in mean eye scores δ for the exposed and control groups which will enable the detection of that difference with a specified probability may be determined by consideration of the magnitude of the observed difference in the rate of change of minor lens defects for these groups and the expected variance of the determinations.

The following terms may be defined to determine the approximate period of observation required to detect an increase in the difference in mean eye scores of the exposed and control groups:

<u>Notation</u>

$\Delta\beta_1 = (\beta_{oe} - \beta_{oc})_1$ = true difference in mean eye scores at time x_1,

$\Delta\beta_2 = (\beta_{oe} - \beta_{oc})_2$ = true difference in mean eye scores at time x_2,

$\delta = \Delta\beta_2 - \Delta\beta_1$

$\Delta\hat{\beta}_1 = (\hat{\beta}_{oe} - \hat{\beta}_{oc})_1$ = estimated difference in mean eye scores at time x_1,

$\Delta\hat{\beta}_2 = (\hat{\beta}_{oe} - \hat{\beta}_{oc})_2$ = estimated difference in mean eye scores at time x_2.

$\hat{\delta} = \Delta\hat{\beta}_2 - \Delta\hat{\beta}_1$

The statistic

$$t^* = \frac{\hat{\delta}}{s_p\left[2\left(\frac{1}{N_e} + \frac{1}{N_c}\right)\right]^{1/2}}$$

$\bar{X}_c$ = 34.3163

SXX_e = 19715

SXX_c = 23880

The F* value at the overall mean age was found to be

F* = 0.0783

which is not significant.

2) The hypothesis Ho was tested at age 60 (i.e., $X_e = X_c = 60$) the same manner as above and the F* value was

F* = 3.8965

and $P\left\{F(1,453) > F^* \ (=3.8965)\right\} < 0.05$

Therefore, the observed difference in mean eye scores at age 60 for the groups, can be said to be statistically significant.

will then be distributed approximately as a t with $N_e + N_c - 2$ = 1293 degrees of freedom under the hypothesis Ho: = 0, and since the number of degrees of freedom is large, s_p may be assumed approximately equal to and the statistic $t^* \doteq Z^*$, i.e., it is approximately distributed as a standardized normal variable.

Therefore,

$$P\left\{ \frac{\hat{\delta}}{s_p\left[2\left(\frac{1}{N_c}+\frac{1}{N_e}\right)\right]^{\frac{1}{2}}} > z_{1-\alpha} \Big/ \delta=0 \right\} \doteq \alpha$$

The power of this test may be determined as a function of δ, $\Pi(\delta)$, as follows $(\delta > 0)$:

$$\Pi(\delta) \doteq P\left\{ \frac{\hat{\delta}-\delta}{s_{\hat{\delta}}} > z_{1-\alpha} - \frac{\delta}{s_{\hat{\delta}}} \Big/ \delta=\delta \right\}$$

where $s_{\hat{\delta}} = s_p\left[2\left(\frac{1}{N_c} + \frac{1}{N_e}\right)\right]^{\frac{1}{2}}$

By use of the tabulated values for the distribution of a normal variable, this expression may be simplified to

$$\Pi(\delta) \doteq 1 - \Phi\left\{ z_{1-\alpha} - \frac{\delta}{s_{\hat{\delta}}} \right\}$$

Substitution of the values, s_p, N_e, and N_c as determined in the regression analysis of the sample of 1295 microwave workers and controls yields the power function, $\Pi(\delta)$, as

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